

Edge Hill University

The Temporal Pattern of Recovery of Eccentric Hamstring Strength and  
Dynamic Stability in Elite Footballers

Thesis Submitted for the Degree of Doctor of Philosophy

by

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## **i) Abstract**

Recent epidemiological data suggests that the incidence of hamstring and ACL injuries are on the rise in football, resulting in significant financial costs to individual clubs. Research has highlighted fatigue, decreased functional strength and reduced dynamic stability as key aetiological factors common to both injuries. Previous research has considered the influence of fatigue on eccentric strength and dynamic stability discretely, but their functional synergy warrants investigation. Furthermore, the fatigue-effect should be considered beyond the acute 90 minutes of match exposure, and consider the temporal pattern of recovery.

In the first experimental chapter (Chapter 4), twenty male professional soccer players (age  $21.50 \pm 3.09$  years, height  $181.98 \pm 5.43$ cm, body mass  $77.73 \pm 5.06$  kg), undertook a localised fatigue protocol until they exhibited a 30% reduction in eccentric hamstring peak torque. Pre fatigue measures of isokinetic eccentric strength ( $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$ ,  $300^\circ \cdot s^{-1}$ , System 3, Biodex Medical Systems, Shirley, NY, USA) and dynamic stability (OSI – Overall Stability Index, A-P – Anterior Posterior Stability, M-L – Medial Lateral Stability, Biodex Medical Systems, Shirley, NY) were taken. These were then repeated at the same time of day post, 24 hr post, 48 hr post and 72 hr post fatigue. Metrics in average peak torque and peak torque were observed to be significantly reduced ( $P \leq 0.05$ ) when compared to baseline levels at +72 hr at the two fastest testing speeds. Significance values indicated that angle of peak torque was fully recovered. Dynamic stability measures of OSI and A-P also remained significantly reduced ( $P \leq 0.05$ ) at +72 hr, whereas M-L scores showed no significance ( $P \geq 0.05$ ) at 72 hr. Quadratic regression analyses revealed unique temporal rates of recovery, requiring up to +82 hr post-exercise. These unique patterns were identified through differentiation of the quadratic regression curve, enabling calculation of the curve minima and the time at which the outcome variable returned to pre-exercise levels.

A similar experimental design was employed in Chapter 5, utilising a soccer-specific fatigue protocol. Eighteen male professional soccer players completed the present study, with a mean age of  $22.94 \pm 4.57$  years, height  $185.38 \pm 4.22$ cm and body mass  $75.91 \pm 6.38$  kg. Average peak torque and peak torque metrics at all speeds were significantly reduced ( $P \leq 0.05$ ) at +72 hr, with no change in angle of peak torque. As with the localised fatigue protocol, dynamic stability measures in A-P were significantly impaired at +72 hr ( $P \leq 0.05$ ) whereas M-L scores were recovered to baseline at 72 hrs. A similar predicted maximum recovery duration of +81

hr was observed following soccer-specific exercise, utilising the same quadratic regression analysis as in chapter 4.

Fourteen male professional soccer players completed chapter 6, (mean age  $24.29 \pm 5.06$  years, height  $184.51 \pm 3.91$ cm, and body mass  $74.91 \pm 4.30$  kg) analysing the effects of soft tissue massage (24 hours post fatigue) on the temporal pattern of recovery post soccer specific fatigue. Sports massage techniques were applied for 20 minutes on the posterior aspect of the dominant limb, with a specific focus on effleurage and petrissage to aid recovery. Results highlighted that all measures for AvgPkt<sub>eccH</sub>, Pkt<sub>eccH</sub> ( $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ) and OSI were all shown to recover within the 72 hr period. The A-P dynamic stability measures were recovered at +48 hr. Time of recovery was calculated with the same quadratic regression analysis completed in chapters 4 and 5. These findings indicate that an intervention of soft tissue massage at 24 hr post fatigue accelerates the recovery process.

An alternate intervention was utilised in Chapter 7, where sixteen male professional soccer players completed a soccer specific fatigue protocol incorporating periods of interchange (mean age  $22.64 \pm 4.70$  years, height  $185.41 \pm 4.72$ cm, body mass  $77.62 \pm 6.08$  kg). The interchange strategy employed was designed to reduce total workload (to 60mins), with each player exposed to a 15 min period of rest in the middle of each half. Peak torque metrics at the two slowest speeds had failed to attain full recovery at +72 hrs, and similarly OSI was still significantly impaired relative to baseline at +72 hrs. Following completion of the same quadratic regression analysis, as completed in previous chapters (4, 5 and 6) the predicted time required for full recovery of all markers was +82 hr. The results of the study highlight that despite reducing the playing time with periods of interchange players had still not fully recovered within the 72 hr period, thus exposing players to potential injury within this time period.

The current thesis is aimed at the sports science and medical teams working within football involved in injury prevention strategies, specific conditioning and rehabilitation. Findings highlight the temporal pattern of recovery post-exercise with specific focus on hamstring function. Simple functional anatomy highlights any decreased function of the hamstring will have implications for potential knee injury, including the ACL. Epidemiological and aetiological research in football continues to be heavily focussed on hamstring strains. This thesis highlights the potential implications that decreased function over a 72 hr period can have on the muscle group, and associated ligamentous structures. Clinical implications of this work

include the periodisation of rehabilitation stages or training micro-cycles, the importance of developing fatigue resistance within players to facilitate a reduction in the occurrence of hamstring and ACL injury, and the development of a more stringent return to play criteria encompassing these biomechanical markers. Evidently, findings within the current body of work suggest that fatigue is an unalterable factor that contributes to injury, but it can be quantified with measures of dynamic stability and eccentric strength. Quantifying fatigue between games with these biomechanical markers provides key information of a player's readiness to play, implications for injury, key time frames to implement interventions and provide key markers to be utilised in the design of return to play protocols post injury.



## **ii) Acknowledgements**

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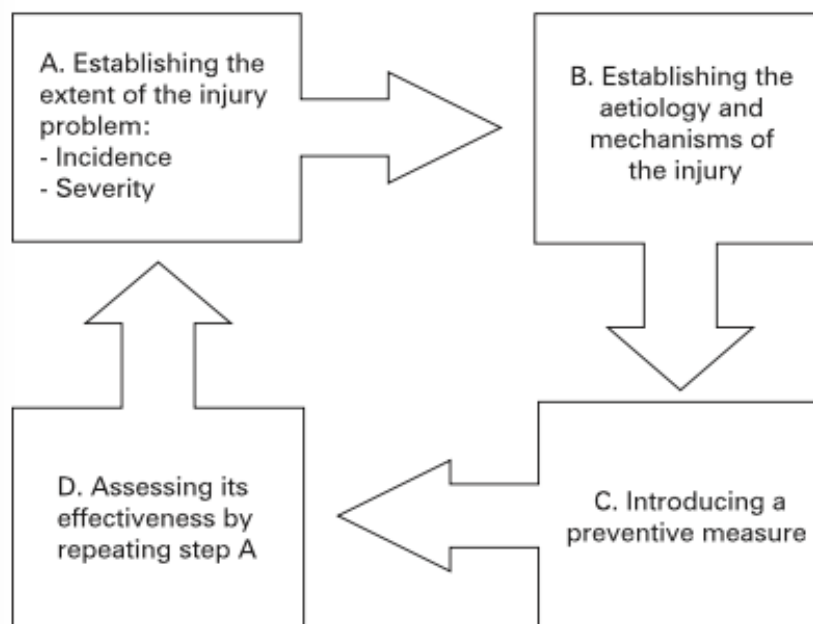
I have to thank my mum and dad, because without their financial and moral support I would not have the job I have nor would I have been in a position to have submitted a thesis. They never said no when it comes to supporting my career or aspirations. I would like to take this opportunity to tell Mr Greenwood, my technology high school teacher, you were wrong! ‘David Rhodes you will never be more than a bin man you are a waste of space, time and energy.’ (Greenwood., 1997). Words that always stayed with me for two reasons, 1) to prove that horrible man wrong and 2) to this day I cannot believe that someone in education would ever be so disrespectful towards hard working people who choose this field of work.

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## **Chapter 1: Introduction**

### **1.1 Overview:**

Epidemiological and aetiological research within football has been well described throughout literature (e.g. Woods et al., 2004; Arnason et al., 2008; Mendiguchia et al., 2012). Evidence has highlighted that there has been no reduction in hamstring injuries over the last decade, with research indicating these are on the rise (Ekstrand et al., 2011, Ekstrand et al., 2016). These findings are consistent with anterior cruciate ligament (ACL) injury within male soccer players, as the prevalence of these injuries has also been shown to have increased (Bjordal et al., 1997; Fauno et al., 2006; Walden et al., 2011; Serpell et al., 2012, Walden et al., 2016). Literature throughout the past decade focussing on preventative strategies for reducing injury has concentrated heavily on altering the associated risk factors, which follows and highlights the use of the Van Mechelen four-step sequence of prevention model (Van Mechelen et al., 1992. Figure 1).



**Figure 1.1:** The Four-Step ‘Sequence of Prevention’ described by Van Mechelen et al., (1992).

The increased incidence of these types of injury within football initiates financial pressures on clubs due to the rising costs brought about by the player being out of action for a significant time period. Early research within football has reported the cost of hamstring injury to clubs within the English Premier League alone escalating to £74.4 million (Woods et al., 2002) and

throughout the whole of English football to £1 billion (Rahnama et al., 2002; Murphy et al., 2003) within a single season. Leaving the assumption that these costs have only risen within recent years, as the incidence of these injuries has increased. These findings in English football are consistent with research in the Australian Football League (Verrall et al., 2006).

Arguments have been developed through literature discussing the main contributory factors to non-contact lower limb injuries. Consistently dynamic stability and eccentric strength are highlighted, with the general consensus being that the issue is multi factorial, involving a huge contribution from both (Askling et al., 2003; Hoskins., 2005; Pizzari et al., 2010; Mendiguchia et al., 2011; Opar et al., 2012). The link between the eccentric strength and dynamic stability has been highlighted by recent injury prevention initiatives such as the FIFA 11+ and the Harmoknee warm up protocols, which have focussed on functional control and strengthening as a method of reducing non-contact musculoskeletal injury (Daneshjoo et al., 2012; Daneshjoo et al., 2013; Barengo et al., 2014; Whitaker et al., 2014; Whitaker et al., 2015).

Commonly hamstring injuries have been associated with low eccentric strength and functionally this reduction has been associated with fatigue (Greig., 2008; Greig et al., 2009; Small et al., 2010; Opar et al., 2012). Fatigue has been highlighted as a key unalterable contributory factor to sustaining non-contact musculoskeletal injury (Ekstrand et al., 2011; Opar., 2012), with a range of metrics used to quantify the aetiological marker (Proske et al., 2001; Greig et al., 2008; Small et al., 2009, Chen et al., 2012). In the current body of work fatigue is to be quantified utilising eccentric strength and dynamic stability, allowing conclusions to be drawn on the effect of fatigue on neuromuscular function. Existing literature in this area focusses on the acute (immediate) effects of fatigue on the athlete and clearly identifies reductions in function when compared to baseline levels (Greig et al., 2008; Small et al., 2009, Gioftsidou et al., 2011. Torres et al., 2012). This research clearly identifies the implications and potential for injury during game play, but does not highlight how players recover over the subsequent 72 hr period post game play. Thus, supporting the use of measures of eccentric strength and dynamic stability as markers of fatigue, but potentially not indicating a player's readiness for game play if they are expected to play twice in a 72 hr period.

Low eccentric hamstrings strength and decreased functional control could have implications for the function of the knee and could potentially increase the chance of sustaining other injuries such as medial collateral ligament damage, anterior cruciate ligament (ACL) strain/rupture and

meniscal, to name a few. The hamstring muscle group act as fixating muscles on the knee to control/restrict excessive forward tibial translation and rotation within the knee, supporting vital stabilising structures such as the ACL. These muscles play a vital role in counteracting the stresses on the ACL when competing (Yu et al., 2007; Melnyk et al., 2007; Sole et al., 2008; Hyun-Jung et al., 2016). Players throughout game play will consistently apply flexion through the knee when performing, when doing this they increase the angle between the tibial shaft and patella tendon, which in turn increases the stress on the ACL in a closed kinetic chain position. It is these stresses that can result in injury to the ACL and not the rotation that can be attributed to the damage, when these stresses are accompanied with rotation then a triad of injury is often sustained. O'Donoghue (1963) stated the triad consisted of damage to the ACL, medial collateral ligament (MCL) and medial meniscus. Shelbourne et al., (1991) disputes this and highlighted that the triad consisted of ACL, MCL and lateral meniscal injuries and very few cases presented with the triad including the medial meniscus. This evidence accompanied with basic functional anatomy highlights the importance of the eccentric strength of the hamstring muscle group in maintaining dynamic stability.

Loading muscle eccentrically causes micro trauma within the muscle fibres and the extent of the damage is dependent on the velocity of contraction (Paddon-Jones et al., 2005; Chapman et al., 2006; Nogueira et al., 2013), which varies constantly throughout a soccer match. Clear indications from research have shown that this results in a decrease in muscle function in relation to proprioception and eccentric muscle strength (Chen et al., 2012; Marshall et al., 2015). Proprioception has consistently been highlighted as being the body's ability to sense movements within joints and to have a knowledge of where these joints are in relation to space. This operational definition within a clinical and evidence based environment can cause some confusion, as measures, tests and exercises actually relate to an effected output and not the physiological proprioceptive process. It is suggested that to actually measure proprioception as a whole function is difficult and as clinicians in sport we are more concerned about the effected output. Therefore, more specificity is required when applying terminology and clarity is needed to determine what is actually being measured. For example, a single leg stand would relate to dynamic stabilisation and recreating angles within joints, joint position sense. Evidence suggests that the micro-trauma exerted by eccentric exercise causes disruption to the muscle spindles and Golgi Tendon Organs; thus affecting an athlete's neuromuscular response, which would explain resultant reductions in eccentric strength and dynamic stabilisation (Proske et al., 2001, Greig., 2008; Opar et al., 2012; Chen et al., 2012). This suggests that

excessive eccentric loading and the resultant fatigue effect experienced in game play can result in decreased eccentric strength and dynamic stabilisation.

It is debated within literature, as to whether fatigue is an alterable or unalterable risk factor associated with injury (Mohr et al., 2004; Opar et al., 2012; Myer et al., 2012; Ekstrand et al., 2016). The discrepancies are a result of the changing effects on fatigue on different populations and individual athletes. Logically, when performing or competing in any sport there will be a resultant fatigue effect, thus making it an unalterable aetiological factor. In a football match the demands of the game can change game by game; in relation to intensities, distances covered and positional changes (Mohr et al., 2003; Stolen et al., 2005). These weekly changing demands can provide great challenge in conditioning athletes. Although fatigue is accepted as an unalterable factor, resultant deficits in strength and dynamic stabilisation that occur as a result of fatigue can potentially be reduced by making athletes more fatigue resistant (Hulin, et al., 2015) and thus enabling fatigue effects to be decreased, but not diminished.

A large proportion of non-contact musculoskeletal injuries are associated with fatigue and this has remained consistently within research as a major contributory factor (Hawkins et al., 2001; Ekstrand et al., 2011; Opar et al., 2012; Ropiak et al., 2012). Research highlights that in soccer these injuries more commonly occur within the final 15 minutes of each half (Proske et al., 2001; Greig et al., 2008; Small et al., 2009; Opar et al., 2012; Chen et al., 2012). Even with this knowledge and the implementation of various preventative protocols, the injury incidence has not decreased; thus, highlighting the need for further research in the field. Consideration needs to be given to the temporal pattern of recovery post fatigue, as this would implicate a player's readiness within a period of congested fixtures. Although there has been research indicating the immediate eccentric strength and proprioceptive responses to game specific fatigue (Greig et al., 2007; Greig., 2008; Greig et al., 2009; Small et al., 2010, Chen et al., 2012) the extent to which these functions are decreased and how long for has not been established.

It is well documented that elite players are often subjected to two games within a period of 72 hr and commonly extending to 3 games in a period of 7 days. This is particularly evident when the club is competing in league and European competitions or players are representing their national teams. This extent of fixture congestion is commonplace throughout all leagues in football from semi-professional rankings to elite level. Research has indicated the detrimental effect this congestion has on players in terms of non-contact injury and evidence has shown

that players who are subjected to successive games within a 72 hr period or less have a higher injury incidence (Dupont et al., 2010; Bengtsson et al., 2014). Research has shown that the immediate team performance is unaffected by periods of fixture congestion (Dupont et al., 2010; Dellal et al., 2013), thus presenting an obvious barrier when discussing leaving players out with coaching staff. This highlights the need for measurable and repeatable biomechanical measures to be established, so medical and science staff can emphasise a player's potential for injury. Examination of the short term effects of fatigue and monitoring these over a 72 hr period would provide a more detailed analysis with regards the temporal pattern, but also where best to inject any intervention/recovery strategy or guide subsequent training protocols. Evidently the hamstring muscle group has a crucial role in supporting and stabilising the knee. If these muscles are functionally weak or neuromuscular function is reduced because of fatigue, then the muscle itself and the knee could be exposed to an increased risk of sustaining serious musculoskeletal injury that can keep players out of competition for an extensive period.

## **1.2 Aims and Structure of the Thesis:**

The aim of the thesis is to investigate the 72 hr temporal pattern of recovery post local (chapter 4) and soccer specific fatigue (Chapter 5) protocols with outcome variables of peak torque ( $PkT_{eccH}$ ), average peak torque ( $AvgPkT_{eccH}$ ), angle of peak torque ( $^{\circ}PkT_{eccH}$ ) and dynamic stability scores in relation to overall stability (OSI), anterior-posterior stability (A-P) and medial-lateral stability (M-L). On identification of the effects of fatigue on these biomechanical markers interventions of soft tissue massage (Chapter 6) and interchange (Chapter 7) will be implemented to analyse the effect they have on the acute fatigue and the subsequent 72 hr temporal pattern, utilising the same markers.

Determining the extent of fatigue induced locally within chapter 5 was designed in relation to findings exhibited in soccer specific fatigue protocols (Greig, 2008; Greig et al., 2009; Small et al., 2009). Within research, the Soccer Specific Aerobic Field Test (SAFT<sup>90</sup>) protocol has been consistently used to simulate soccer specific fatigue and it is evident that this protocol results in biomechanical deficits that will expose the athlete to an increased chance of injury (Small et al., 2009). The extent of this fatigue in relation to percentage decrease of peak torque (PkT) can be utilised as a marker for eliciting localised fatigue on the hamstrings (Chapter 4). Subjecting the hamstring muscle group to this will highlight the local deficits in relation to biomechanical function on the hamstrings and indicate the potential impact this will have on

the knee joint. It will also allow for comparisons to be drawn, identifying if this fatigue generates the same deficits in these biomechanical functions, in relation to the temporal pattern post fatigue.

Evidently reduction in eccentric strength (Mair et al., 1996; Small et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Delextrat, 2010) and the resultant decreased dynamic stabilisation that occurs as a result of fatigue (Askling et al., 2003; Arnason et al., 2008; Rees et al., 2008; Petersen et al., 2011) are two key contributory factors to hamstring and ACL injury. The effects of sport specific fatigue protocols have shown these reductions throughout and immediately post game play, thus identifying the acute effects of fatigue on these biomechanical functions (Lattinziio et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Riberio et al., 2010; Thomas et al., 2010; Gear 2011; Changela et al., 2012). All of the listed literature discusses and draws conclusions on the acute effects and does not examine the temporal pattern post fatigue. Chapter 5 will analyse the acute effects of soccer specific fatigue (SAFT<sup>90</sup>), but will continue the observation of biomechanical markers over the subsequent 72 hr temporal pattern. It is common place in soccer for players to experience periods of fixture congestion and successive games can be completed within a 72 hr period. This is evident in league and cup fixtures, but also on the international circuit in tournaments. These periods have been shown to increase the injury incidence rate of players, although not affecting overall performance (Dupont et al., 2010; Dellal et al., 2013; Bengtsson et al., 2014). Examination of the temporal pattern of eccentric hamstrings strength and dynamic stability is essential for identifying the chance of a player sustaining such injuries as hamstrings or ACL, but also highlighting key windows to implement interventions/recovery strategies to try to accelerate this recovery process.

Determination of the temporal pattern post localised (Chapter 4) and soccer specific (Chapter 5) fatigue will identify an appropriate time-period to intervene with soft tissue massage (Chapter 6) to analyse the effects this has on recovery. Soft tissue massage is a common intervention used across numerous sports (Cafarelli 1990; Moraska 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Portillo-Soto et al., 2014) and this modality is commonly used within football as a recovery tool post event. There are inconsistencies to when this should be implemented to have the greatest effect and research is contradictory to whether massage has any effect at all (Cafarelli 1990; Best et al., 2008; Micklewright 2009; Portillo-Soto et al., 2014). It is suggested that whether it is effective or not is potentially associated

with the importance of when it should be delivered and the clinician who is delivering the massage? Attempts will be made within the thesis to identify where an intervention of soft tissue massage would be best placed and the effects of this being applied on the 72 hr temporal pattern post fatigue will be analysed. The methodology will give consideration to existing flaws within current research, which include delivery of the massage, experience of the clinician, techniques applied and duration applied for (e.g. Tidus, 1999; Galloway et al., 2004; Nelson et al., 2013).

Chapter 7 will analyse the effect interchange injected in to the SAFT<sup>90</sup> protocol has on the acute effects of fatigue, but also the subsequent temporal pattern. Interchange within Australian Football League (AFL) and rugby league has been evidenced to be a successful tool in combating the acute effects of fatigue (Gabbett., 2005; Orchard et al., 2011; Orchard., 2012; Orchard et al., 2012). It is commonplace within these sports to substitute a player when they are fatigued and allow them to re-enter the game after a period of recovery. This is not something that is implemented in professional soccer. The use of interchange within chapter 7 of the thesis will see two 15-minute periods of recovery injected in to the SAFT<sup>90</sup> protocol, where the player will be withdrawn from the protocol to rest. Evidence exists supporting the need for this to be explored within football, as the incidence of non-contact musculoskeletal injuries and more specifically hamstring injuries in AFL have been decreased as a result of implementing interchanges within the game (Orchard et al., 2011; Orchard et al., 2012). The successful implementation of interchanges within AFL and rugby league has contributed to a reduction in non-contact hamstring injuries (Orchard et al., 2012; Orchard et al 2013). It seems logical to suggest that such a rule change and an introduction of interchanges within football could potentially have the same effect. A study within the thesis will introduce interchanges in to the SAFT<sup>90</sup> protocol and its effect on the 72 hr temporal pattern post fatigue of eccentric strength and dynamic stability will be examined.

The significance of the thesis is to develop the current body of work regarding the effects of fatigue on eccentric strength and dynamic stability and how successful intervention strategies attempting to reduce the effects of fatigue are. Conclusions drawn from this research will guide preventative processes. This will provide a greater understanding of the multi factorial nature of the contributions to non-contact musculoskeletal injury in the knee and the significance of these findings will give guidance of interventions, periodisation of training, rehabilitation post ACL semitendinosus autograft surgery and prevention strategies implemented in the future.



## Chapter 2: Review of Literature

### 2.1 Introduction:

Injury prevention strategies are formulated by assessing the injury incidence/severity, its aetiology, developing methods to help prevent the injury and assessing the effectiveness of these strategies employed on injury occurrence (Van Mechelen et al., 1992, figure 1.1). The Van Mechelen preventative model has been further developed in more current research with Finch., (2006) proposing the TRIPP method (see figure 2.1) and Verhagen et al., (2010) promoting the importance of behaviour mechanisms in the strategy of intervention.

Model stage	TRIPP	van Mechelen et al 4 stage approach [1]
1	Injury surveillance	Establish extent of the problem
2	Establish aetiology and mechanisms of injury	Establish aetiology and mechanisms of injury
3	Develop preventive measures	Introduce preventive measures
4	"Ideal conditions"/scientific evaluation	Assess their effectiveness by repeating stage 1
5	Describe intervention context to inform implementation strategies	
6	Evaluate effectiveness of preventive measures in implementation context	

Figure 2.1: Comparison of The Translating Research into Injury Prevention Practice (TRIPP) Framework for Research Leading to Real World Sports Injury Prevention and The Van Mechelen Model (1992). Finch., (2006)

Finch's (2006) method highlights the importance of evidence-based research informing practice and utilising this within developing preventative methods. Alternatively, Verhagen et al., (2010) integrates the behaviours of important bodies and roles, which influence preventative interventions for players, which is a key consideration when developing preventative strategies for decreasing injury occurrence (see figure 2.2).

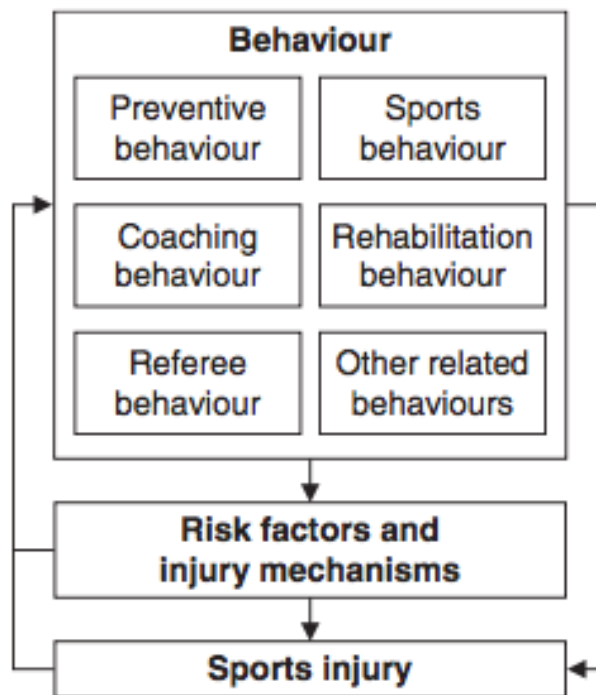


Figure 2.2: A Conceptual Model of the Relationship between Behavior, Injury Risk Factors and Injury Mechanisms, and Sports Injury. Verhagen et al., (2010)

Ultimately, within any preventative measure it is reliant of the compliance of the athlete or coaches developing the rehabilitation training protocols, for it to be successful. Van Tiggelen et al., (2008) highlight this in their preventative model (see figure 2.3). It is evident that the simplistic model designed by Van Mechelen (1992) provides the foundations for all preventative strategies employed to combat troublesome injuries in sport and to this day provides an excellent grounding for research design into interventions and preventative protocols implemented by researchers or medical teams. This model has provided the bases for the study design within the thesis. However, it is important to acknowledge the extensions of the Van Mechelen Model (1992), proposed by Finch., (2006), Van Tiggelen et al., (2008) and Verhagen et al., (2010), emphasise important considerations that were also taken in to

account within the thesis. As compliance, study design and influencing bodies behaviours provide key contributions to the injury prevention process (McCall et al., 2015).

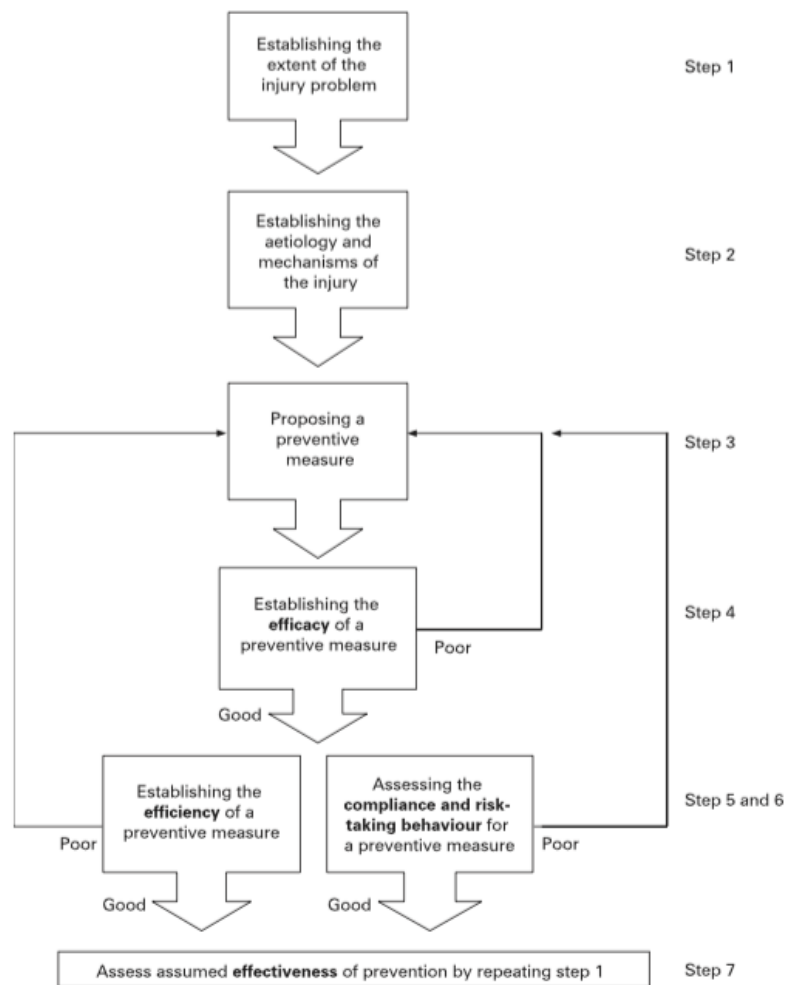


Figure 2.3: Sequence of Prevention of Overuse Injuries. Van Tiggelen et al., (2008)

The following review aims to focus on discussing the epidemiology and aetiology of hamstring and ACL injuries. Within the review, consideration will be given to injury incidence, common mechanisms of injury and the effects of fatigue on eccentric strength and dynamic stability (an element of proprioception). Discussion will also include current intervention strategies utilised in football and other related sports; analysing how these interventions may contribute to a reduction in injury incidence. These factors will be further discussed in relation factors that need to be considered with regards biomechanical markers for return to play post non contact musculoskeletal injury.

## **2.2 Epidemiology:**

### ***2.2.1 Hamstring Injuries:***

The hamstring muscle group is one of the most frequently injured muscle or tendon groups seen in athletes, particularly in sports that involve running, jumping or kicking (Orchard et al., 1997; Woods et al., 2004; Gabbe et al., 2006; Arnason et al., 2008; Engebretsen et al., 2010; Pizzari et al., 2010; Mackey et al., 2011; Opar et al., 2012; Mendiguchia et al., 2012; Serpell et al., 2012; Ropiak et al., 2012; Orchard et al., 2012; Ekstrand et al., 2016). These injuries alone in the English Premier League have been shown to cost clubs in the region of £74.4 million in a single season and £1 billion across the whole of English Football (Rahnama et al., 2002; Murphy et al., 2003; Woods et al., 2004). Recent indications in research illustrate that hamstring injury incidence has increased (Hawkins et al., 1999; Hawkins et al., 2001; Ekstrand et al., 2011; Ekstrand et al., 2016) and the rising finance the English game brings would indicate that this figure is even higher in the modern game. These findings are considered within the Australian Football League where increasing costs of hamstring injuries to clubs has been highlighted (Verrall et al., 2006; Hickey et al., 2014). Costs to clubs are heightened by the time lost by players through injury. Hamstring injuries have been shown to result in considerable time lost on the pitch and in training, with evidence detailing up to 80 days lost per team per season (Orchard 2009., et al; Engebretsen et al., 2010; Ekstrand et al., 2011; Ekstrand et al., 2016), which ultimately could have a negative effect on the performance of the team.

Ekstrand et al., (2016) highlighted that the incidence of hamstring injury has not been decreased, indicating that there has been a 4% increase annually since 2001 and 22% of players sustaining at least one hamstring injury per year. Common non-contact injuries sustained by athletes in elite football that are associated with the knee are hamstring strains/tears; with research indicating that they are now more common than lateral ankle sprains and have an incidence rate of 12 – 16% of all injuries (Arnason et al., 2008; Woods et al., 2004; Arnason et al., 2008; Engebretsen et al., 2010). These papers also indicated that the majority of hamstring injuries were sustained in game play with an incidence of 3.0 – 4.1 hamstring strains per 1000h; of match play and 0.4 – 0.5 per 1000 h; of training. It is important to note that these incidence rates were taken from varying populations across Europe; thus producing varying statistics. It is important to note the findings from each piece of research displays similar statistics between population groups falling between a 4% range; thus indicating that the incidence of hamstring

injury has never fallen across European football populations, ultimately becoming an increased expense to football clubs.

Ekstrand et al., (2011) monitored injury incidence and type of injury over a 7-season period in Europe's top football clubs and indicated that 12% of all injuries sustained in football were associated with the hamstrings. They averaged, that per team, these injuries were sustained by at least 8 players per season accounting for a total of 37 days lost per player; again highlighting the severity of the problems associated with this injury. Although all of the mentioned epidemiological research clearly highlights the severity of the issue surrounding these injuries it does not indicate potential strategies for reducing the occurrence of these injuries nor is it suggestive of potential aetiological factors associated with injury.

Epidemiological research in this field also identifies that the recurrence of a hamstring strain is between 12 - 31% (Anastasi et al., 2011; Mendiguchia et al., 2012). This suggests that the methods implemented within pre-habilitation and rehabilitation are ineffective or not fully implemented by medical teams within football clubs due to pressures of returning the athlete to play post injury or limited time given within training schedules. It is also recognised that because of the slow healing process, persistence of symptoms and high re-injury rates hamstring strain injuries are the most frustrating injuries to medical staff, coaches and athletes (Petersen et al., 2005; Croisier et al., 2008; Ekstrand et al., 2011).

### ***2.2.2 ACL Injuries:***

Poor function within the upper thigh and particularly the hamstring muscle group can contribute to injury being sustained in the knee (Walden et al., 2011; Hewett et al., 2013; Kim et al., 2016). Research has identified fatigue, hamstring strength and 'proprioception' as being key contributory components (Roberts et al., 2004; Vathrakokilis et al., 2008; Aletorn-Geli et al., 2009; Walden et al., 2011; Silva et al., 2012; Serpell et al., 2012; Shelbourne et al., 2013; Hewett et al., 2013; Kim et al., 2016; Hyun-Jun et al., 2016). Common knee injuries sustained in training and game play reported in research are; medial collateral ligament injuries (MCL) at 11%, meniscal injuries at 11% and ACL injuries contributing to 46% of all ligament injuries within the knee (Rahnama et al., 2009). In cases where the player sustains a rupture of the ACL, it is highly likely that the MCL and the meniscus is damaged, which is highlighted in research as the O'Donoghue's Triad (Fisher et al., 2011; Yoon et al., 2011). Although debate

exists to which meniscus is damaged evidence has indicated that it is more commonly the lateral meniscus (Shelbourne et al., 1991).

It has been reported that the incidence of ACL injury ranges from 0.06 to 3.7 per 1000 hours, which includes training and game play (Bjordal et al., 1997; Bollen 2000; Fauno et al., 2006; Yu et al., 2007; Brophy et al., 2010). Current evidence highlights that there has been no epidemiological data in the last 10 years to show a decrease in injury prevalence in male athletes (Orchard et al., 2001; Renstrom et al., 2008; Walden et al., 2011; Serpell et al., 2012; Hewett et al., 2013). Interestingly it is also reported that re-injury of the ACL post-surgery is not uncommon and this may be attributed to inadequate rehabilitation or return to play criteria (Myer et al., 2012; Shelbourne et al., 2013; Hewett et al., 2013). Research into epidemiology, aetiology and management of ACL injury has been heavily focussed on female athletes. Increased risk has been attributed to female soccer players, which may go some way to explaining the large range in incidence research (McNair et al., 1990; Arendt et al., 1995; Hewett et al., 1999; Agel et al., 2005; Renstrom et al., 2008; Myer et al., 2009; Brown et al., 2009; Littman et al., 2012).

Some aetiological factors reported in the aforementioned research can be identified as gender specific, for example hormonal difference, Q-angle, inter-condylar notch width. This said, associated factors contributing to injury and key focuses within preventative programs are strength asymmetry, decreased functional strength and poor dynamic stabilisation (Daneshjoo et al., 2012, Daneshjoo et al., 2013, Barengo et al., 2014, Whitaker et al., 2014, Whitaker et al., 2015). Renstrom et al., (2008) reports that the percentage occurrence of ACL injuries in relation to all injuries sustained on female football teams to be 3.7% compared to 1.3% on male football teams. Impact of these injuries in male soccer cannot be understated. Walden et al., (2011) reported in a three-cohort study involving Swedish men's and women's professional league and several professional men's European leagues that non-contact ACL injuries had an incidence rate of 58% over an 8-season period, highlighting that 95% of all ACL injuries occurred in match play. Thus highlighting, that regardless of gender, the occurrence rates of ACL injuries in males are significant enough to increase the financial burden on clubs and potentially be detrimental to the team's performance, due to significant lay off times. This has been further emphasised in recent seasons within English professional football with the high rate of ACL injuries sustained at Burnley FC (5 players in 18 months, 2014-2015), Liverpool

FC (3 players in 12 months, 2014-2015) and Everton FC (5 players in 12 months 2008-2009), to name a few.

## **2.3 Overview of Aetiology:**

### ***2.3.1 Hamstring Injuries:***

Generally, the semitendinosus and semimembranosus muscles within the hamstring group play a key role in restricting unwanted movements during selected sporting actions. Semimembranosus provides general stability to the knee and semitendinosus provides rotatory valgus stability to the knee; combined they act as an agonist to the ACL providing rotatory and anterior stability, which is a key component that aids reduction in knee injuries. (Ropiak et al., 2012).

Research has investigated many areas to explain why frequency of hamstring injuries has failed to be reduced and the contribution of these factors to lower limb injuries, specifically around the knee (Agre., 1985; Verrall et al., 2001; Askling et al., 2003; Peterson et al., 2005; Brooks et al., 2006; Gabbe et al., 2006; Croisier et al., 2008; Arnason et al., 2008; Henderson et al., 2009; Pizzari et al., 2010; Engbretsen et al., 2010; Goldman et al., 2011; Mendiguchia et al., 2012; Opar et al., 2012; Cross et al., 2013; Ahmed et al., 2013; Ekstrand et al., 2016). Throughout this literature consistently discussed are two categories of factors associated with hamstring injuries, unalterable (fatigue, age, gender, race, ethnicity and previous injury) and alterable risk factors (flexibility, biomechanical, strength imbalances and proprioceptive function). In addition to this the relationship between recurrence of injury and neuromuscular inhibition was discussed heavily in relation to atrophy of the hamstrings, reduction in functional strength (eccentric) following injury and the contribution of neuromuscular function. It was also suggested that this dysfunction could also lead to other non-contact musculoskeletal injuries within the knee. Although, this does highlight an area for concern, the literature examined did not discuss the effects of fatigue on neuromuscular function and whether the resultant effect contributes to changes in the functional strength of the athlete. It is also important to note that although the unalterable factors cannot be changed, certain factors like age and its influence on strength deficits can be reduced as a result of specific training (Askling et al., 2003; Fousekis et al., 2010; Anastasi et al., 2011; Candow et al., 2011; Daneshjoo., 2013).

It is clear within current evidence that reductions in functional (eccentric) strength is a major contributory factor to sustaining a hamstring injury (Pincivero et al., 2000; Willems et al., 2002; Thomas et al., 2010; Rampinini et al., 2011) and this reduction in eccentric strength can be brought about by soccer specific fatigue (Greig., 2008; Greig et al., 2009; Small et al., 2009). Strength has been quantified within research utilising isokinetic dynamometry (IKD) and a key marker to quantify functional strength is eccentric hamstring peak torque ( $PkT_{eccH}$ ) (Koller et al., 2006; Greig 2008; Greig et al., 2009; Small et al., 2009). Small et al., (2009) also identifies the importance of measuring angle of eccentric peak torque ( $^{\circ}PkT_{eccH}$ ), as this can be attributed to the functional significance of the  $PkT_{eccH}$  measure. Extension of these measures could potentially focus on an  $AvgPkT_{eccH}$  value. This value would identify torque elicited through a given speed on the IKD and average a torque value through the measured speed. This measure would then identify how much torque is elicited through range, but also then be comparable to the  $PkT$  and where in the range this is exhibited.

Exerting strength output is reliant on an efficient neuromuscular response. If the neuromuscular response is inhibited or delayed during performance, or more specifically an acceleration/deceleration action, this could result in overstretch or overload of the hamstring muscles. Neuromuscular response or delay has been strongly associated with non-contact muscle injuries such as hamstrings (Askling et al., 2003, Arnason et al., 2008, Rees et al., 2008, Petersen et al., 2011). Further to this fatigue and subsequent by products of fatigue have been shown to desensitise mechanoreceptors resulting in a delay in the signal to initiate a response (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). This again emphasises the importance of understanding fatigue as an aetiological factor and research into the 72-hour temporal pattern post fatigue in relation to the biomechanical markers of eccentric strength and dynamic stabilisation.

### ***2.3.2 ACL Injuries:***

Literature surrounding ACL injuries clearly highlights that the majority of cases are sustained through a non-contact mechanism (Feagin et al., 1985; Boden et al., 2000; Yu et al., 2007; Serpell et al., 2012). The contributing factors to these mechanisms have been discussed and debated within literature, but like hamstring injuries can be separated in to alterable (biomechanical, neuromuscular response and functional strength) and unalterable factors



(fatigue, age, gender and previous injury) associated with sustaining injury (Yu et al., 2007; Hewett et al., 2008; Alentorn-Geli et al., 2009; Brophy et al., 2010; Myer et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015). It is evident that within the literature, female players are more likely to sustain this injury due to gender influences and biomechanical make-up of the female body, which alters loading through the knee (e.g. Hewett et al., 1999; Renstrom et al., 2008; Myer et al., 2012; Croix et al., 2015). These factors include hormonal difference, Q-angle and inter-condylar notch width, which are all non-modifiable risk factors. It is important to highlight that research in this area has been exhausted and conclusively emphasises the same aetiological factors contributing to sustaining an ACL injury (e.g. Fauno et al., 2006; Holly et al., 2011; Bryant et al., 2011; Serpell et al., 2012). Research within this area for male athletes does display some similar aetiological factors. It is important to note that some of these factors, i.e. unalterable aetiological factors, such as age are contradictory to the findings in female athletes (Serpell et al., 2012). The majority of evidence surrounding ACL injuries in male athletes focuses towards the neuromuscular response and strength deficits within the hamstring muscle group (e.g. Arnason et al., 2013; Meybodi et al., 2013; Harput et al., 2015; Kim et al., 2016). These two key aetiological factors are modifiable, gender neutral and consistently documented within research.

Reductions in eccentric strength of the hamstring muscle group can potentially increase the vulnerability of the ACL during performance (Myer et al., 2009; Bryant et al., 2010; Arnason et al., 2013). This is based on the basic knowledge of functional anatomy and acknowledgement that the hamstring muscle group is a key stabiliser of the knee. A key factor that has been shown to effect hamstring function is fatigue and the acute effects of fatigue on eccentric hamstring strength are well documented (Mair et al., 1996, Small et al., 2008, Greig., 2008, Greig et al., 2009, Small et al., 2009, Delextrat, 2010). Thus, if there are considerable reductions in eccentric strength of the hamstring muscle group, as shown within soccer specific research (Greig., 2008; Greig et al., 2009; Small et al., 2009), then the potential for injury to the ACL is increased. Comparisons can be made between aetiological factors of injury for hamstring and ACL. This is due to the similarity between how these injuries are commonly sustained through a deceleration sagittal movement pattern.

To effect an efficient response and for the muscle to elicit the required functional strength on demand the athlete relies on the effectiveness of the neuromuscular response. If there is a delay in the neuromuscular response, then this will alter the torque output exerted by the muscle

during performance. This reduction in strength can potentially reduce the dynamic stabilisation of the knee, a factor that has been strongly associated with knee and specifically ACL injury (Hiemstra et al., 2001; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Cordeiro et al., 2014; Lee et al., 2015). Fatigue is a key factor that is associated with reductions of eccentric strength (Pincivero et al., 2000; Willems et al., 2002; Sangnieer et al., 2007; Wright et al., 2009; Thomas et al., 2010) and dynamic stabilisation of the knee (Meznyk et al., 2006; Riberio et al., 2008; Thomas et al., 2010; Gioftsidou et al., 2011; Changela et al., 2012). Evidence suggests that the bi products associated with fatigue can desensitise the mechanoreceptors within the muscle (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Freddolini et al 2015) and this may explain why during performance or post event athlete's exhibit reductions in strength or stability. It is clear that these two aetiological factors are key contributors to both ACL and hamstring injuries. It is also noted that fatigue contributes significantly to reductions in these both through and immediately post performance. Research focuses on the acute effects of fatigue on these contributory factors. A greater understanding is required of the temporal pattern post fatigue. More focus is required on the effects of fatigue and the resultant temporal pattern post fatigue making comparisons between dynamic stabilisation and eccentric strength.

### ***2.3.3 Comparisons of Hamstring and ACL Aetiology:***

Research highlights neuromuscular function in relation to functional strength, dynamic stability and fatigue as key contributory factors for both ACL and hamstring injuries (Arnason et al., 2008; Letafatkar et al., 2009; Henderson et al., 2009; Pizzari et al., 2010; Moussa et al., 2009; Myer et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015; Ekstrand et al., 2016). Thus, proposing that if the functional strength of the hamstrings was decreased as a result of fatigue, this would result in a decreased dynamic stabilisation of the knee, which would potentially leave both the hamstrings and ACL exposed to injury. This would be increased within performance as a result of the increased load placed through these structures when playing. Literature in both fields analyses the acute effects of fatigue on these aetiological factors and there is a gap in the research to examine the temporal pattern post fatigue, up to a period of 72 hours. This would allow conclusions to be drawn with regards potential implications of injury in a period of fixture congestion commonly experienced by clubs within a season, but also indicate when best to apply any intervention.

Comparing aetiological factors for sustaining hamstring and ACL injuries in male soccer players emphasises similar findings and it would seem logical to forge a link between sustaining the two injuries when discussing alterable and unalterable factors contributing to injury. Resultant deficits in strength experienced by the hamstrings as a result of fatigue (Sangnieer et al., 2007; Greig., 2008; Small et al., 2009) have been associated with an increased risk of sustaining a hamstring injury, as a result of the muscle being unable to sustain the eccentric load exerted through it when performing. This reduction in function could also be attributed with a reduction in dynamic stability. Although literature indicates this is potentially the case, as fatigue results in a reduction of proprioception (Hiemstra et al., 2001 Ribeiro et al., 2008; Torres et al., 2010; Ribeiro et al., 2010; Changela et al., 2012), comparisons of these measures on the same group have not been made, proposing the question does fatigue elicit similar effects on both biomechanical measures?

#### **2.4 Unalterable Aetiological Factors: Hamstring and ACL Injuries:**

Clear links within literature have shown that the age of the male footballer has been linked to increased risk of hamstring (Orchard., 2001; Verrall et al., 2001; Henderson et al., 2009; Goldman et al., 2011; Mendiguchia et al., 2012) and ACL injury (Orchard et al., 2001; Agel et al., 2005; Alentorn-Geli et al., 2015). This is contradictory to findings in females (Soligard et al., 2008; Renstrom et al., 2008; Hewett et al., 2008; Brophy et al., 2010; Anastasi et al., 2011; Myer et al., 2012; Croix et al., 2015). It is evident that research has highlighted that males were more susceptible to these non-contact musculoskeletal injuries in their mid to late 20's, whereas females were more likely to sustain injury in their late teens to early 20's. Reasons for this have been linked to hormonal changes in females and their development. Although these suggestions cannot be dismissed, it is feasible to suggest that the effects of these contributions to injury can be decreased. The testing procedures utilised within the research completed were based on common screening methods utilised within clubs to identify player's risk of injury. These testing procedures included; functional and concentric strength measures performed on the IKD; isometric strength of quadriceps and hamstrings; calculations of eccentric hamstring to concentric quadriceps ratio ( $H_{ecc} : Q_{conc}$ ) and concentric hamstring to concentric quadriceps ratio ( $H_{conc} : Q_{conc}$ ) ratio; flexibility measures of hamstrings; dynamic stability measures including Star Excursion Balance Test (SEBT), Y balance and BSS; biomechanical measures including Q angle and pelvic/postural position. Player's injuries were then noted through a

season and correlations were identified. Predominantly correlations identified were related to reductions in dynamic stabilisation and eccentric strength.

Gabbe et al., (2006) utilised 222 elite players for analysis which were separated into two testing cohorts ( $\leq 20$  years and  $\geq 25$  years), each player was then screened utilising 6 tests which included anthropometric testing, lumbar, hip, knee and ankle mobility and neural testing. Player's participation rates in training and games were then monitored, non-involvement in these because of sustaining injury was recorded and comparisons of the age groups were made to identify differences in injury occurrence and whether the observed differences were predictors of hamstring injury. Differences were identified between the age groups and it was identified the older athlete was at an increased risk of sustaining a hamstring injury. As discussed earlier, age is an unalterable risk factor to injury and is associated with decreased function in relation to reductions in functional strength and dynamic stabilisation. It is suggested and noted that by training these particular components the effects of age can be decreased. It is evident that Gabbe et al., (2006) study does not consider many other factors that could contribute to injury and if identified within screening, individual plans can be implemented to change precursors of injury that have been identified. All tests utilised to screen the players in their study can be related to alterable factors, for example decreased flexibility, and decreased mobility. If specific interventions were implemented then it is possible that this would have reduced the risk of injury to players, potentially highlighting that specific training protocols need to be in place for older players to reduce non-contact musculoskeletal injuries. Similarly research into gender and ethnicity highlight similar concerns (Woods et al., 2004; Agel et al., 2005; Chappell et al., 2005; Brown et al., 2009; Cross et al., 2010). Although these factors need to be taken into consideration when completing research, it is evident these contributions to injury (age, gender and ethnicity) can be individual to that group or player and are also linked to alterable factors (flexibility, strength and proprioception). This suggests individualising a player's programme taking into account these factors would reduce the chance of sustaining a non-contact hamstring or ACL injury.

Previous Injury is another unalterable factor attributed to recurrence of ACL and hamstring injuries. Occurrence of these injuries can result in deficits of strength, mobility neuromuscular function and bilateral asymmetry. Post sustaining an ACL rupture the athlete will be subjected to surgery, commonly a semitendinosus or patella tendon autograft. This surgery has been demonstrated to cause deficits in strength and proprioception (Landes., et al 2010; Nagai et al.,

2013; Myer et al., 2012; Lee et al., 2015; Kim et al., 2016). Similarly, research post hamstring injury has resulted in similar findings (Crosier et al., 2008; Mackey et al., 2011; Opar et al., 2012). Conclusively, the research highlighted has emphasised that there is a deficit in the player's function post injury. It is important to acknowledge that the deficits that are detected in athletes post injury can remain throughout the rehabilitation process and are indicated as alterable factors; most notably being proprioception and strength. It seems plausible to suggest that previous hamstring or ACL injury remains a factor and a precursor for re-injury. Therefore suggesting that this could be a result of insufficient rehabilitation. Potentially, the length of time for recovery may have been too short due to pressures on the player to return or the return to play criteria itself was not stringent enough to ensure the player was fully functional before return. It is therefore suggested that any preventative or predictive markers of injury could formulate markers within the rehabilitation process.

Arguably, the most significant unalterable aetiological factor is fatigue (Greig., 2008 and Small et al., 20010). Competition or training within football will result in fatigue and a resultant deficit in function (Greig., 2008; Greig et al., 2009; Small et al., 2009; Small et al.; 2010). The extent of fatigue elicited through training and competition may vary dependent on game demand or drills/exercises completed (Ekstrand et al., 2011; Opar., 2012). Interpretation of the extent of fatigue experienced will differ within professionals working in science and medical departments in football. It is essential to be able to quantify the resultant fatigue effect. Marshall et al., (2015), emphasised the importance of this within their research indicating that 5 Nordic hamstring curls can significantly increase a player's susceptibility to injury. The debate of whether fatigue is an alterable or unalterable risk factor continues. It is understood that fatigue occurs and will always occur within competition and training, it is the resultant effect on function, i.e. functional strength and dynamic stability, that needs to be the focus in research (Greig., 2008; Small et al., 2010; Ribeiro et al., 2010; Changela et al., 2012). Knowledge of this has led academics and clinicians to propose that if the fatigue effect on these biomechanical functions is reduced through specific training and conditioning then the fatigue effect can be altered. However, these interventions have seen no reduction in hamstring (Woods et al., 2004; Ekstrand et al., 2016) or ACL (Bjordal et al., 1997; Walden et al., 2016) injuries in the last decade, potentially highlighting the gulf between research and practice in football. Alternatively, it may support the notion that fatigue is unalterable. Prompting the need for a greater understanding of the temporal pattern post fatigue and the fatigue-effect on alterable

aetiological factors that require specific conditioning to increase the fatigue resistance of the athlete (Hulin et al., 2015).

## **2.5 Alterable Aetiological Factors Hamstring and ACL Injuries:**

There are many alterable factors that have been highlighted in recent research that contribute to hamstring and ACL injury, these include decreased proprioception, decreased strength, decreased flexibility and poor biomechanical control; to name a few (Agre., 1985; Verrall et al., 2001; Askling et al., 2003; Peterson et al., 2005; Brooks et al., 2006; Gabbe et al., 2006; Yu et al., 2007; Hewett et al., 2008; Alentorn-Geli et al., 2009; Croisier et al., 2008; Arnason et al., 2008; Henderson et al., 2009; Pizzari et al., 2010; Engbretsen et al., 2010; Brophy et al., 2010; Goldman et al., 2011; Mendiguchia et al., 2012; Myer et al., 2012; Cross et al., 2013; Ahmed et al., 2013; Alentorn-Geli et al., 2015; Croix et al., 2015; Ekstrand et al., 2016). It is accepted that fatigue is an unalterable risk factor, as any involvement in training or competition will elicit a fatigue effect (Greig, 2008; Small et al., 2010; Ribeiro et al., 2010; Changela et al., 2012). Fatigue is the factor that is heavily associated with non-contact musculoskeletal injury, due to its effect on alterable aetiological factors associated with injury (Hewett et al., 2008; Greig., 2008; Engbretsen et al., 2010; Opar., 2012; Alentorn-Geli et al., 2015). Literature predominantly highlights that non-contact musculoskeletal injuries occur in the later stages of the game; thus emphasising that fatigue is a main contributory factor (Pincivero et al., 2000; Willems et al., 2002; Sangnier et al., 2007; Wright et al., 2009; Thomas et al., 2010; Rampinini et al., 2011).

The effects of fatigue on flexibility are unclear, as research has been mainly focussed on correlations between flexibility and injury and the effect of utilising flexibility training as an intervention strategy to reduce muscular injury. Findings from this research have been contradictory between papers, but also when analysing the results, thus suggesting that flexibility alone is not a key contributory factor to injury (Orchard et al., 1997; Bennell et al., 1999; Gabbe et al., 2002; Witvrouw et al., 2003; Bradley et al., 2007; Henderson et al., 2009). Indications within these papers have suggested that fatigue results in a reduction in flexibility. Due to the nature of the evidence produced, it is unclear if this results in an increased chance of sustaining injury. Commonly in practice, clinicians have been led to think that the tighter the hamstring the increased chance there is of injury, due to the inability of the muscle to lengthen comfortably through sporting motion. Although this is feasible, an alternate theory

could be that the muscle only becomes vulnerable if the muscle cannot withstand the load it is being subjected to within its range. Suggesting that flexibility and its contribution to injury are relative to its functional muscle strength.

During game play and functional movement patterns players are heavily reliant on the neuromuscular response (stretch-reflex response) to protect the muscles from overstretch and the joints from abnormal load, that ultimately result in injury (Hewett et al., 1999; Myer et al., 2012; Herman et al., 2012; Croix et al., 2015). When performing movements, the athlete is reliant on the afferent signals sent from the mechanoreceptors in joints and muscles (Muscle Spindles, Golgi Tendon Organs (GTO's), Ruffini Endings, Ruffini Corpuscles and Pacinian Corpuscles) to generate the effected response required to protect the structures from injury (Zimny., 1998; Hogervorst et al., 1998; Greig et al., 2007; Letafatkar et al., 2009; Cordeiro et al., 2014). If the flexibility of the athlete is increased and the athlete has the ability to generate an increased ROM (range of movement), which is not accompanied with an improvement in their functional strength, then they may be increasing their chance of injury (Witvrouw et al., 2003; Rahnama et al., 2005; Ivan et al., 2011; Geux et al., 2016). Theoretically, an increased flexibility could result in a delayed neuromuscular response and ultimately an electromechanical delay (EMD) of the afferent signal; thus delaying the response of the muscle to correct the movement (Esposito et al., 2010; Jensen et al., 2013; Warren et al., 2014). If this occurs then the joint may be allowed to move into an abnormal movement pattern. This could result in an increased chance of ACL injury. Alternatively, the EMD may result in the muscle being overstretched, resulting in the player sustaining a hamstring strain. This theory is based on consideration of the physiological processes required to control functional movement patterns. Thus promoting the suggestion that functional strength and control through movement becomes a more important contributing factor than flexibility and any rehabilitation should focus on increasing the length-tension relationship in the muscle tissue (Brocett et al., 2001; Proske et al., 2001; Proske et al., 2005). If the muscle is functionally strong enough to sustain the load of the movement, it is being subjected to and it is fatigue resistant then the likelihood of sustaining a muscle strain or associated non-contact musculoskeletal injury is decreased. This increased strength within the hamstrings would also provide an increased stability within the knee; thus reducing the chance of sustaining an ACL injury.

Eccentric strength is the most common type of strength that has been associated with injury (Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2010;

Thomas et al., 2010; Rampinini et al., 2011) and it is common practice within football clubs to employ eccentric strengthening methods as part of their preventative strategies or within rehabilitation post injury (Willems et al., 2002; Paddon-Jones et al., 2005; Cavanaugh et al., 2012; Laurin et al., 2011; Petersen et al., 2011; Lorenz et al., 2011; Molina et al., 2012; Harput et al., 2015). The use of eccentric training is based on the theory that many lower limb injuries occur when a functional movement is performed requiring eccentric control. Consequently, if the player is trained eccentrically this will increase their tolerance to the load applied during game play (Arnason et al., 2008). This seems a plausible and simplistic suggestion. It is important to note the incidence of lower limb injury in sports that include sprinting, running, jumping and other associated activities that have high acceleration/deceleration loads has not decreased. Research now suggests that these types of musculoskeletal injuries are now more prevalent than ankle injuries, accounting for 12-16% of all soccer related injuries (Hawkins et al., 1999; Hawkins et al., 2001; Woods et al., 2004; Ekstrand et al., 2011; Goldman et al., 2011; Ekstrand et al., 2016). Thus, highlighting that a multifactorial training approach is required.

Current research has been conclusive in this area over the last decade, indicating that fatigue of the hamstrings results in a reduction in eccentric strength (Pincivero et al., 2000; Willems et al., 2002; Koller et al., 2006; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011). Significantly Koller et al., (2006); Greig (2008); and Small et al., (2010) examined hamstrings strength in relation to functional game or event protocols. Koller et al., (2006) focussed their research on eccentric hamstrings strength in marathon runners, while the other three papers studied the effect of soccer-specific fatigue protocols and their effect on eccentric hamstrings strength. Similar conclusions were drawn from all studies with them all stating that the fatigue protocols resulted in a reduction of eccentric hamstrings strength and this was a pre cursor for hamstring injury. It is important to note that during a marathon run the athlete will progress steadily through the energy systems through the race and predominantly will utilise the aerobic energy system. Soccer players will be reliant on all energy systems throughout the duration of the 90 minutes. Thus providing clear evidence that whether the fatigue is induced by a specific game protocol or by a marathon protocol the resultant effect is the same. Fatigue of the hamstrings and a decrease in hamstrings strength indicates that the hamstrings become more susceptible to injury, but can also leave the knee susceptible to sustaining other injuries, as the hamstrings are main stabilising muscles of the knee. This said all studies by Koller et al., (2006); Greig., (2008); and Small et al., (2009) all analysed the immediate effects of fatigue



and not the temporal pattern post. This is important to note as fatigue is something that occurs as a result of game play and reductions in strength and stability would be expected. However, the temporal effects of this fatigue are arguably more important, as this details a player's readiness to play the next game or complete the desired training.

Specific research within footballers (Greig., 2008; Greig et al., 2009; Small et al., 2010) has shown that soccer specific fatigue results in a 20- 30% deficit in eccentric hamstrings muscle strength. This decrease has been significantly attributed to being a key contributory factor that results in injury. Careful consideration was given within each of these studies to key factors that can contribute to reductions in strength, one of which was the time of day the testing was completed. This remained consistent for each player throughout testing and replicated timings they were familiar to training or playing in. Time of day (circadian rhythm) has been shown to have significant effects on strength profiles of players (Drust et al., 2005; Bambaiechi et al., 2009; Bougard et al., 2010; Blanc et al., 2010; Malhorta et al., 2014). This presents its own difficulties in the modern game, as the variety of times of day that players perform is vast and when competing in European and International football time differences can also be significant; thus creating a greater range of timings when players perform. Arguably, if the player sustains a good strength profile then regardless of the time of day they will still reduce their chance of a non-contact musculoskeletal injury.

The effects of fatigue on hamstring to quadriceps strength ratio (H: Q) have been analysed from two perspectives. The conventional ratio; which is the concentric hamstring to concentric quadriceps ratio ( $H_{con}: Q_{conc}$ ) and the dynamic control ratio (functional ratio); which is the eccentric hamstring to concentric quadriceps ratio ( $H_{ecc}: Q_{conc}$ ) (Wright et al., 2009; Delextrat et al., 2010; Cheung et al., 2012; Opar et al., 2012; Hyun-Jung et al., 2016). Research has identified that fatigue has been shown to increase both ratios; thus increasing the athlete's potential of sustaining a musculoskeletal injury (Wright et al., 2009; Delextrat et al., 2010; Cheung et al., 2012; Opar et al., 2012; Hyun-Jung et al., 2016). More recent research has contradicted the findings of these studies; highlighting that neither the conventional nor the functional H: Q ratios showed a significant difference post fatigue, but more notably there was a significant difference in the peak force values of each muscle group (Camarda et al., 2011; Greco et al., 2012). This emphasises that there is an equal reduction in quadriceps and hamstrings peak torque as a result of fatigue. Evidently, these deficits would result in an increased risk of injury for the player in the quadricep and hamstring muscle groups and also

leave the ACL vulnerable, due to changing forces applied by the musculature (Hiemstra et al., 2001; Williams et al., 2001; Melnyk et al., 2007; Cordeiro et al., 2014).

Anatomically there is an imbalance between the anterior and posterior myology of the upper thigh and it is normal to expect a difference in peak torque between the two muscle groups (Rosene et al., 2001; Wright et al., 2009; Delextrat et al., 2010; Cheung et al., 2012; Opar et al., 2012; Hyun-Jung et al., 2016). A normative and accepted difference between the two muscle groups is well documented and when this ratio is increased this has been associated with an increased chance of non-contact injury (Wright et al., 2009; Delextrat et al., 2010; Cheung et al., 2012; Opar et al., 2012; Hyun-Jung et al., 2016). The evidence presented in this thesis suggests an increase in this ratio and an imbalance between the two muscle groups would be one factor that would imply why the hamstrings are the muscle group that is the most frequently injured. This would also explain why the ACL is exposed, as the hamstrings act as a stabiliser for the knee and restrict excessive anterior tibial translation (Ageberg et al., 2009; Yeow et al., 2013; Nacierio et al., 2013). Eccentric strength of the hamstrings has to be a key focus within preventative strategies, but this strength needs to be consistent through range. If this is achieved, then the H(ecc): Q(conc) ratio will be reduced and the ACL and hamstrings will be less susceptible to injury. This is very simplistic, but due to the ever-changing demands in the modern game, the effects of fixture congestion and the resultant cumulative fatigue caused by this, a greater understanding of the temporal pattern post fatigue needs to be developed and its effect on key biomechanical pre-cursors of injury, as this will provide insight how these factors can be reduced.

Proprioception is another factor that is commonly associated with knee injuries and particularly injuries to the ACL (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). Evidence has highlighted that players with a decreased amount of proprioceptive control through specific sporting movements are more susceptible to injury (Ogard., 2011; Mir et al., 2014). The term proprioception is widely used in research and cited in several different contexts and the accuracy of this terminology used to describe measures is questionable.

Al-Dadah et al., (2010) titled their paper 'Proprioception following Partial Meniscectomy in Stable Knees.' The methodology of this study incorporated the use of the Biodex Balance SD

System (Biodex Medical Systems Incorporated, Shirley, New York) to measure proprioception. It is clear that this does not represent a measure of proprioception, but it quantifies a component of proprioception. Dynamic stability is a neuromuscular response/output for an athlete to maintain their body position and results in a muscle contraction to stabilise body position through variations of joint load (Williams et al., 2001; Cordeiro et al., 2014). The testing procedure within the study gives no indication of the neurological contribution of the participant to create the response, it just provides an output score based on dynamic stability performance. Adjustments in body position to maintain stability clearly have a neuromuscular contribution, but where this is initiated is undetectable from this test. Arguably, it is more important to measure the efficiency of the output in maintaining stability rather than which mechanoreceptors are initiating the response. It is suggested that this is a functional measure that could indicate a player's risk of injury, which presents vital information for the clinician. A more appropriate title for the paper would have been 'Dynamic Stability following Partial Meniscectomy in Stable Knees.' This is evident throughout literature and has been demonstrated in the research completed by Roberts et al., (2004) and Sekir et al., (2007). Both pieces of research cited in the titles that they were measuring proprioception, but the outcome measure was single leg balance (dynamic stability) and joint position sense (recreation of an angle through sensation), respectively; again emphasising the lack of clarity or the generalist nature of the research in current literature. This presents the question; does research need to demonstrate a better understanding of the element of proprioception that is being measured?

Proprioceptive control is made up of a number of components that will allow an athlete to correct movement patterns; these include receptors within joints, ligaments, muscles, tendons, skin, visual and vestibular sensation that all feedback to the central nervous system (CNS) to effect a response (Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009). It is evident that there are clear links between strength and components of proprioception. Analysing the evidence presented with regards the functional strength of the muscle, it seems plausible to argue that the strength will only provide stability and control if the neuromuscular pathway is highly efficient. Regardless of how strong the muscle maybe (Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Greig, 2008; Adachi et al., 2009; Greig et al., 2009; Small et al., 2009). If these pathways are not efficient and the player is subjected to an EMD, then the result will be abnormal high load movements through the knee or overstretching of the hamstring muscle, resulting in a strain (Ristanis., 2009; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015;

Freddolini et al 2015). When assessing the effects of fatigue on functional control, it is suggested that by measuring the dynamic stability of the lower limb and the eccentric strength of the hamstrings, this potentially would give a better indication to the risk of injury and also allow assumptions to be made with regards to the efficiency of the neuromuscular pathway.

The mechanoreceptors are key components of the afferent pathway and in theory, for the effected muscle response to influence a change in muscle length or an adjustment of the movement pattern an understanding of the key constituent of proprioception that is being identified for development/improvement must be established. Currently, as clinicians, we have no measurement technique that distinguishes, which afferent response was received by the CNS to cause a response. A muscle can be subjected to an overstretch as a joint moves in to an abnormal position. It is highly likely that proprioceptive responses from the mechanoreceptors in the knee joint are accompanied by signals from the muscle spindle and golgi tendon organs in the muscle to prevent this (Melenyk et al., 2007; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). Theoretically, there will be a cross of pathways between the afferent signal from the mechanoreceptors in the knee and those from the muscle spindle and golgi tendon organ (GTO). Thus, negating the above argument and suggesting that by improving the neuromuscular pathways through treatment or training protocols will result in an improved affected output.

Distinguishing, which pathway is initiating the resultant effected response is arguably unimportant. Determining the effectiveness of the response to correct abnormal movement patterns or overstretch is key (Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). To amend any abnormal movement within the knee (proprioception) or reducing overstretch (stretch-reflex) is achieved through a contraction of the muscle itself, either to hold and stabilise or to shorten and adjust (Melenyk et al., 2007). Although, there is no differentiation to highlight which afferent signal stimulates an effected response and which receptor(s) this signal is coming from, it is clear that the correction of movement is brought about by a muscular response (neuromuscular control). A good measure of this is through determining the player's dynamic stability (Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). The effected response is for a muscle contraction to occur to correct abnormal movement, thus decreasing the chance of injury (Grigg., 1994). Any detection in change or requirement to correct an abnormal movement is reliant on the strength

of the muscle effecting the change, but also the reliance on the speed of the efferent response; thus highlighting the relationship between the two. If there is any EMD then the athlete is exposed to an increased chance of injury, either to the joint or muscle tissue. It is important to note cardarvic research has also indicated that the ACL has fewer mechanoreceptors contained within it when compared to the surrounding structures within the joint (Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009). This may also contribute to the electromechanical delay, and this accompanied with decreased muscle function, as a result of fatigue, would expose both structures to potential injury.

Due to the inaccuracies used in terminology and the emphasis, being focussed around the response of the muscles to abnormal movement patterns or overstretch; it is evident that the majority of measures of proprioception within research are studies that determine effected responses through muscle contraction. A key effected response of the body to abnormal movement is dynamic stability (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008 Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). It is important to note that dynamic stability is not proprioception as a whole, but it is a response (component of proprioception) to maintain position to stop abnormal movement patterns within the knee. It is also important to acknowledge that the dynamic stability is only effective if the muscle is strong enough to withstand the load it is subjected to and that the neuromuscular pathways are highly efficient (Greig, 2008; Adachi et al., 2009; Greig et al., 2009; Small et al., 2009). The hamstrings are a key muscle group that aid and maintain stability within the knee. The efficiency of this is reliant on the muscle group being functionally strong (Pincivero et al., 2000; Willems et al., 2002; Koller et al., 2006; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011). If it is not strong and cannot affect an eccentric contraction to correct movement patterns, then the result will either be a muscle strain/tear or the knee will not be stabilised and anterior translation and over rotation will occur; thus resulting in an ACL rupture with common associated joint injuries or a strain of muscle tissue. Although, the current research has highlighted proprioceptive measures as pre cursors of injury (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015) and discussed hamstring and ACL injury in relation to functional strength (Pincivero et

al., 2000; Willems et al., 2002; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011), these measures have not been combined to determine fatigue effects. A combination of these two main contributory factors would provide a more detailed outline of a player's potential of sustaining injury and could be integrated into a players return to play criteria.

### ***2.5.1 Eccentric Strength:***

There have been several areas of focus for recent research associated with eccentric strength and injury within the hamstrings. Some of these include the benefits of eccentric training in relation to football, linking to conditioning, rehabilitation and prevention of injury. Research has consistently demonstrated that eccentric strength training of the hamstrings was effective in reducing, preventing and decreasing reoccurrence of hamstring injuries; thus highlighting the importance of its integration within conditioning programmes for players (Askling et al., 2003; Arnason et al., 2008; Mackey et al., 2011; Petersen et al., 2011). As previously discussed, audits have highlighted that the occurrence of these injuries in football have not decreased and suggestions have been made that they are on the rise (Woods et al., 2004; Arnason et al., 2008; Ekstrand et al., 2011; Ekstrand et al., 2016). The current demands within the modern game are high; this accompanied with an increased fixture demand could potentially be a major contributory factor. Future research must pay consideration to this and investigation into temporal patterns post fatigue would give a clearer indication of how best to manage these factors, as current research heavily focuses on the acute effects of fatigue (Greig., 2008; Wright et al., 2009; Small et al., 2009; Thomas et al., 2010; Rampinini et al., 2011).

Eccentric training has become a major focus when formulating any preventative or rehabilitative programme (Willems et al., 2002; Paddon-Jones et al., 2005; Anastasi et al., 2011; Laurin et al., 2011; Petersen et al., 2011; Lorenz et al., 2011; Molina et al., 2012; Cavanaugh et al., 2012; Harput et al., 2015). Research has shown that the benefits of this conditioning on the hamstrings has demonstrated the potential to reduce lower limb injuries in football. Inclusive of ACL injuries, due to the functional control and stabilisation this strength provides within the knee (Askling et al., 2003; Koller et al., 2006; Arnason et al., 2008; Rees et al., 2008; Petersen et al., 2011; Lorenz et al., 2011; Anastasi et al., 2011; Cordeirio et al., 2014). These papers focussed on the implementation of eccentric training protocols and methods of increasing eccentric strength and emphasised the influence this had on non-contact

musculoskeletal injury. They clearly highlighted the benefits of eccentric training, but there was no indication of when they need to be implemented or how they can be successfully periodised in to training through the season. This may indicate why incidence of non-contact hamstring and ACL has not been reduced (Woods et al., 2004; Arnason et al., 2008; Ekstrand et al., 2011; Ekstrand et al., 2016). These studies clearly demonstrate that there is a clear link between the reduction of eccentric strength and neuromuscular function due to fatigue; however, further investigation in to the understanding of the temporal pattern of this fatigue must be developed. This would allow the training, either preventative or rehabilitative, to be periodised more efficiently; thus ensuring the player is subjected to overloading these systems through training to build fatigue resistance, but within safe and controlled parameters. This knowledge is also essential within the modern game as it is now commonplace for players to be expected to play three games in the period of 7 days. There is very little evidence that highlights the length of time it takes the hamstrings to return to their pre-eccentric exercise function or if repeated eccentric loading increases the length of time it takes a player to return to these levels. Consequently, indicating that after the muscle has been subjected to repeated bouts of eccentric loading and post exercise the muscle is not given enough time to return to its pre-exercise state, then the athlete is at an increased risk of injury.

Research clearly indicates that there is a decrease in eccentric strength as a result of fatigue (Mair et al., 1996; Small et al., 2008; Greig, 2008; Small et al., 2009; Delextrat, 2010). Small et al., (2008) and Greig and Siegler, (2009) findings concluded that as a result of fatigue sustained through game play a player is more susceptible to a hamstring injury at the later stages of each half, as there is a clear decrease in eccentric hamstring peak torque. These findings could have been extended and it is suggested that this resultant decrease in eccentric hamstrings peak torque, also decreases the stability the hamstrings provide to the knee through functional play and high load movement patterns. Arguably, if there is a decrease in functional strength of the hamstrings then this would decrease the load it could endure, thus decreasing the ability of the muscle to stabilise the knee.

The decrease in eccentric peak torque in the studies undertaken by Greig et al., (2008) and Small et al., (2009) was shown to be between 20 – 30 % at all speeds tested on the Isokinetic Dynamometer (IKD). This is a clear indication of the immediate negative effect of fatigue on strength. It is suggested that there is a bigger picture due to the multi factorial nature of hamstrings and ACL injury and the fact that these types of injuries have not been decreased

(Hawkins et al., 1999; Orchard et al., 2001; Hawkins et al., 2001; Renstrom et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Hewett et al., 2013; Ekstrand et al., 2016).

Evidence outlines links between functional strength and proprioception with injury, as separate entities. Only combined effects are analysed in systematic reviews of literature, where it is suggestive that these injuries are a result of a combination of factors, as discussed earlier (Pincivero et al., 2000; Willems et al., 2002; Koller et al., 2006; Sangnier et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011). This has led to presenting questions of whether the fatigue effects are similar for eccentric strength and dynamic stabilisation in the lower limb and how long does it take for these biomechanical functions take to return to normal levels post exercise? The significance of this information cannot be over stated, as it would inform the training protocol designed by the medical and coaching staff for players.

Consideration must be given to previous eccentric overload through game play/training and the length of time it takes an athlete to recover from this; otherwise the players' susceptibility to a hamstring or ACL injury is increased in the following fixture. Literature that examines recovery post fatigue mainly focuses on nutrition/supplementation, interventions to accelerate recovery and how long it takes the physiological systems to return to base line levels (Willems et al., 2002; Etheridge et al., 2008; Hedayatpour et al., 2010; Molina et al., 2012). There seems to be a lack of understanding of the temporal pattern of recovery post fatigue structured around biomechanical measures. It is clear that there are deficits of eccentric strength and 'proprioception' as a result of fatigue (Mair et al., 1996; Askling et al., 2003; Arnason et al., 2008; Small et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Delextrat, 2010; Rees et al., 2008; Petersen et al., 2011). Understanding how these biomechanical functions change over a 72-hour period post fatigue would develop knowledge of the player's readiness for game play in a period of continuous games, but also highlight where potential interventions should be employed to combat the effects of the fatigue or how training and rehabilitative programmes need to be periodised.

Various measures have been used throughout research to quantify muscle strength; these include 1RM (1 rep max) single leg and double leg squats, dynamometry and isokinetic testing (Dauty et al., 2001; Drouin et al., 2004; Maffiuletti et al., 2007; Impellizzeri et al., 2007; Greig.,



2008; Hazdic et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015). These tests are carried out to give an outcome measure and it is this measure, if low compared to normative values, which has been attributed to an increased risk of non-contact musculoskeletal injury. Due to the significant cost of hamstring injuries in football (Rahnama et al., 2002; Murphy et al., 2003; Woods et al., 2004), the reliance of the hamstring muscle group on stabilisation of the knee and the mechanism of injury associated with hamstring and knee injuries. Isokinetics has become the main testing procedure utilised to quantify functional strength of the hamstring muscle group (Gaines et al., 1999; Dauty et al., 2001; Dauty et al., 2003; Drouin et al., 2004; Svensson et al., 2005; Maffiuletti et al., 2007; Impellizzeri et al., 2007; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011). Svensson et al., (2005) states in their review of testing procedures in football that the IKD is focussed on one muscular area of the joint, which limits the functionality of the testing. Although this is true it is important to note that this limitation can be overcome by how the data collected is applied and combination testing within the IKD can provide more applied functional data. The consistent use of this method of measurement throughout rehabilitation to quantify improvements in athletes indicates the importance clinicians place on this as a tool to monitor progression. The information gathered tends to be heavily focussed on the eccentric knee flexor torque at varying speeds (Dauty et al., 2003; Askling et al., 2008; Hazdic et al., 2010; Delextrat et al., 2010; Fousekis et al., 2010) due to the IKD showing good test-retest reliability (Steiner et al., 1993; Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015). It is important to note that this reliance on the measure of PkT is limited. To increase the functionality of the measures gained from the IKD, clinicians can also incorporate the °PkT, AvgPkT in relation to the speed of testing and also the range of angle to which the torque is achieved (Svensson et al., 2005; Greig., 2008; Greig et al., 2009; Small et al., 2009). Analysing these, as a whole would provide a more informed view of the strength of the hamstrings and allow assumptions to be made about the individual's potential to sustain injury when performing functionally.

Two of the most common isokinetic dynamometers utilised in practice are the Cybex and Biodex systems. Ribeiro et al., (2015) analysed 770 knee flexor and extensor isometric, concentric and eccentric measures of strength and indicated testing on the machines had high to very high reproducibility of measures ( $r = 0.88$  - Cybex and  $0.92$  - Biodex). They also concluded peak torque measures between machines did not show great differences amongst

them. There have been several pieces of research discussing the reliability and validity of the IKD as a strength measurement tool and it is consistently highlighted that it has high reliability and validity  $r = 0.9 - 0.98$ . (Steiner et al., 1993; Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015). All of this research was completed on both eccentric and concentric strength profiles at a variety of speeds ranging from  $30^{\circ}\cdot s^{-1}$  to  $180^{\circ}\cdot s^{-1}$ .

Common mechanisms of injury for the hamstrings and ACL are related to high loads and high speeds where control is exerted either during an acceleration/deceleration phase or change of direction; thus suggesting a need for profiling to be done at higher speeds to replicate these demands. Eccentric IKD measures at  $300^{\circ}\cdot s^{-1}$  have often been questioned in relation to how much of the ROM represents 'true' isokinetic measures. Although, this may be true this may be a key indicator and preventative measure associated with reducing hamstring and ACL. If the participant cannot demonstrate a good ROM profile at this speed, it may highlight that they are more prone to sustaining injury associated with high velocity mechanisms. Drouin et al., (2004) highlighted that any measures up to  $300^{\circ}\cdot s^{-1}$  showed good reliability and validity, which was also reiterated by Greig., (2008). Drouin et al., (2004) profiling was done utilising calibrated weighting on the IKD and not human subjects. Even though this was the case, it highlights that if a player can match the demands of the machine at these speeds and control movement then the measures obtained are likely to be very good. If they cannot meet these demands then maybe it would suggest that the player is not functionally ready to return to game play, as these would be similar if not slightly less than loads experienced during game play (Gaines et al., 1999; Greig., 2008). It is suggested that because of the increased functionality of performing at a higher speed and the suggested reliability and validity of these measures, testing should be completed at this level. It is also important to incorporate a slow  $60^{\circ}\cdot s^{-1}$  and mid speed  $150^{\circ}\cdot s^{-1}$ , as this gives an indication of the requirements the athlete requires in a rehabilitation or pre-habilitation protocol. This would facilitate their return from injury or identify strategies for decreasing potential injury markers. In theory if a player has a weaker eccentric strength profile across all speeds then they would be more likely to sustain a hamstring or ACL injury when playing (Pincivero et al., 2000; Willems et al., 2002; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011). This is because the hamstrings would not respond to the changes in length at pace making them more susceptible to overstretch; nor would they be able to apply enough functional control to stabilise the knee through fast, high load

movements (Ribeiro et al., 2008; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015).

Several studies have utilised the use of peak eccentric knee flexor torque as a marker to indicate the potential risk of sustaining a hamstring injury (Dauty et al., 2003; Koller et al., 2006; Maffuletti et al., 2007; Greig 2008; Delextrat et al., 2009; Hazdic et al., 2010; Findikoglu et al., 2011; Greco et al., 2013). Each of the studies listed have variations in the protocol they complete in relation to the speeds assessed, which range from  $60^{\circ}\cdot\text{s}^{-1}$  to  $300^{\circ}\cdot\text{s}^{-1}$ . Although, patient position, range of movement through flexion-extension and how the patient is stabilised in the machine to ensure maximum peak torque is generated is consistent throughout, and has been shown to increase the validity of the measures taken. Research has commonly analysed PkT values when assessing functionality in relation to strength. PkT is a value that can be achieved within 1 degree of movement or it is something that can be sustained for a succession of degrees within that isometric contraction. However, when analysed the values will present the same. When assessing a squad this could leave athletes presenting with the same profile, when in reality the ones that can sustain PkT for a period of degrees would demonstrate a better strength profile through range. Taking this in to consideration it seems logical to analyse the AvgPkT within the isometric testing speeds in relation to PkT, as this would give the assessor a better picture of the athlete's strength profile.

Commonly, in all of the studies listed the patient is strapped in to the IKD stabilising the torso, pelvic region, thigh and the attachment of the lever arm is strapped to the lower leg, 2-3cm proximal of the malleolus of the tested limb. Research has shown that if the athlete is not suitably strapped in to limit compensatory bodily movements then the output given for the peak torque is reduced (Weir et al., 1996). Another common practice when setting the IKD is to ensure the trunk is set at 15 degrees (Delextrat et al., 2009; Findikoglu 2011). Variations of settings are found when looking at hip angle with some researchers setting at 85 degrees (Dauty et al., 2003; Maffuletti et al., 2007; Cheung 2012; Greco et al., 2013) and others at 90 degrees (Heuser et al., 2010). The range of movement of the knee used shows the largest amount of variety from the studies reviewed, with some research showing ROM of 70 degrees and others utilising ROM of up to 110 degrees. It is acknowledged that when measuring PkT range of movement (ROM) through flexion-extension will be determined by the athlete's comfort and is also affected by whether the participant is injured. By doing this you will also reduce any neural stretch applied to the nerve pathways (sciatic nerve) supplying the hamstring

muscle group, which consists of the tibial and common fibular nerve. This said there may be variety within the study between the ROM achieved by each participant, but this will allow an athlete to perform at their maximum potential generate maximum force through movement in relation to the speed of the test. Further research has examined the importance of knee joint alignment with the axis of the IKD and its effect on PKT output. It concluded that knee extension peak torque did not significantly change when the knee joint was misaligned with the axis of the dynamometer. It was found that knee flexion PKT was significantly affected when the knee was moved away both horizontally and vertically from the centre of the axis of the dynamometer (Houweling et al., 2010). Thus, emphasising the importance of correct knee position when setting the athlete up in the IKD.

When testing at a variety of speeds, the order in which this is completed varies with many papers looking to move from slow to fast speeds (Dauty et al., 2003; Koller et al., 2006; Maffuletti et al., 2007). The issue developed from this is the testing protocol becomes predictable and falls further away from the demands of the game. Functionally, when performing players will work between slow and fast speeds, but there is no set pattern in which they will work. It seems logical to vary the order in which the testing speeds are presented to replicate these demands on the muscular system. Greig., (2008), Small et al., (2009) and Greig et al., (2009) utilised a 3-speed measure in this order at  $180^{\circ}\cdot s^{-1}$ ,  $300^{\circ}\cdot s^{-1}$  and  $60^{\circ}\cdot s^{-1}$ . The purpose for the variation between speeds is contradictory to recommendations of working from slow to fast, as they felt during the familiarisation period players tested were placing more importance on later trials, rather than producing equal effort throughout. They also, felt by varying the presentation of the speeds they were closer to replicating the demands of football specific activity, as the loading during a game does not move from slow to fast each time and maximal power output is required at a variety of speeds. Accompanying this with the variation of data observed from the eccentric output of the hamstring further progresses the functionality of the data and allows an application to be made to game specific demands, but also to draw deeper conclusions with regards the players functionality within the rehabilitation and pre-habilitation process.

Another consideration when trying to maximise the output/effort of the performer when being tested on the IKD is whether or not to provide the athlete with verbal or visual encouragement. Enoka (1992), McNair et al., (1996), Kim et al., (1997), Gandevia (2001), Knicker et al., (2011) indicated through their research the use of visual feedback through the computer system and

verbal encouragement both maximised effort of the athlete. Recent research has not included these elements in their project design (Greig., 2008; Greig et al., 2009; Small et al., 2009) and it may need to be considered in future research, as the reality for a footballer is to receive constant feedback when performing. Implementing feedback has been shown to maximise performance and for footballers is a familiar process that they experience when performing, in training or working with the science and medical teams in prehabilitative or rehabilitative work. Due to player familiarity of this during game play and training it seems logical to include this feedback within testing to provide the players with the encouragement required to maximise their performance, as it would contribute to them achieving a maximal output. This would determine whether the performer's peak torque was decreased because of psychological (central fatigue) or physical fatigue (peripheral fatigue); as we know that motivation, self-efficacy and anxiety can decrease performance (Williams et al., 2002; Hall et al., 2005; Hu et al., 2007; Rampinini et al., 2007; Crewe et al., 2008).

### ***2.5.2 Dynamic Stability:***

As discussed earlier proprioception has been loosely utilised as a term or outcome measure in relation to fatigue and research has demonstrated a lack of understanding within their discussions around the studies completed. This could be a main contributory factor to why contradictory conclusions have been made with regards proprioception and fatigue; thus, emphasising the need to be accurate and transparent, to what is actually being measured in future research.

Gioftsidou et al., (2011) found that there were no deficits in proprioception, but there was a decrease in isokinetic knee joint moment measurements in the flexors and extensors in the knee pre and post training in soccer. They stated that there is no link between fatigue induced soccer training and injury caused by impaired balance. There was no indication within this study of the intensity of the training and whether or not this replicated the demands of game play. The paper separated JPS and balance as two separate components and did not associate balance with proprioception. Due to the physiological proprioceptive system, if JPS is decreased in the athlete, theoretically the balance would be affected, as it implies that there is a decrease in function of the afferent/efferent pathway and mechanoreceptor detection and the effected response. The findings from this research were contraindicated by Gear (2011) and Changela et al., (2012), who found that mild, moderate and maximum fatigue have a significant effect on

knee joint proprioception. These findings were also supported by earlier studies from Riberio et al., (2008 and 2010) who investigated the effects of volleyball specific fatigue on knee joint position sense. They found that post volleyball game play, elite volleyball players had a marked effect on decreased joint position sense; Lattinzo et al., (1997), Meznyk et al., (2006) and Thomas et al., (2010), present further evidence in their research to support the detrimental effect of fatigue on proprioception. Thomas et al., (2010) also stated that decreased proprioception, as a result of fatigue is a marker and indicator for potential injury. It is clear that within this literature proprioceptive outcome measures are commonly made utilising two methods either through the Joint Position Sense (JPS), dynamic stability/balance. Although these outcome measures will highlight the proprioceptive ability of the player/athlete being tested, it needs to be accepted that we can only be indicative of why the athlete has a poor/good performance during these testing protocols and therefore actually addressing what is actually being measured should be highlighted and discussed in any reporting of the findings. The measures will only give us an effected output and not the receptive process the mechanoreceptors stimulate when initiating the afferent signal to the CNS. The main variations within research come from how the quantifiable measures of JPS and dynamic stability are achieved. Arguably, if the effective output or dynamic stability is improved post fatigue then the collective proprioceptive physiological process will be improved and due to the functionality of dynamic stability to game play this would highlight it as a key measure to quantify the proprioceptive function of the athlete.

Joint Position Sense (JPS) relates to the athlete's perception of the position of a joint with their vision occluded and minimal feedback given. Clinically, JPS is often referred to as proprioception. Various studies have utilised the IKD to determine the subjects JPS within research (Tsiganos et al., 2008; Surenkok et al., 2008; Paschalis et al., 2010; Philippou et al., 2010; Ribeiro et al., 2010; Yan Ying et al., 2010; Gear 2011; Cug et al., 2012; Jurevičienė et al., 2012; Littman et al., 2012; Torres et al., 2012; Silva et al., 2012). Measures of JPS are commonly taken on the IKD and can be completed at slow or fast velocity. When completed at an increased speed the participant is to make a judgement on when the joint is positioned at the pre-determined angle, alternatively at slow velocity the subject needs to move the joint to the pre-determined angle and hold, pausing the IKD with an abort button (Littman et al., 2012). From a functional perspective the IKD does not factor in high loads or movement at high speed and the subject's proprioceptive response to these factors. This needs to be taken in to consideration when designing a protocol to test muscle function based on the measurement of

proprioceptive response in relation to footballers. Even though this is accepted as a key consideration when designing the protocol of a study, research has shown the use of the IKD to measure JPS to be reliable (Drouin et al., 2004). Measuring JPS with the use of the IKD is limited in terms of functionality, as the replication of the angles dictated by the machine at given velocities do not replicate the movement patterns experienced in game play. The importance of the measure of JPS has been highlighted within literature as it emphasises how much movement the knee is experiencing and the link between the central nervous system and the output of motor control. The use of JPS for proprioceptive assessment in orthopaedic patients is rare (Cordo et al., 1995; Verschueren et al., 2002; Shields et al., 2005). This could be associated with 2 factors the first being the accessibility of the equipment and the other being how functional this measure is, which is clearly a concern within soccer when attempting to identify indicators for injury in relation to muscle function.

There have been several functional measurements used to quantify muscle function in relation to proprioception, performance and muscle activity; the most notable being the single leg hop (Benjaminse et al., 2008). The single leg hop test correlates positively with muscle strength (Lephart et al., 1992; Wisloff et al., 2004; Yosmaoglu et al., 2011) and is not a stand-alone measure of proprioception; therefore, highlighting that it must be combined with other quantifiable measures to give a definitive measure of proprioception. It is essential to highlight that the landing from the single leg hop does simulate rapid deceleration, which research has shown us to be a key mechanism of injury in sporting activity (Boden et al., 2000). Evidence highlights several different combinations to gain a quantifiable measure of proprioception. Changela et al., (2012) combined force platform measures with photographic evidence of the knee movements through the sagittal plane of movement. Although quantifiable, this only gave an indication of joint position sense in relation to the movement's flexion and extension, but no measurement was made for medial or lateral motion of the knee. Further research in to measures of knee proprioception identified that an electrogoniometer gives a quantifiable measure of knee JPS (Lattanzio et al., 1997). However, this again only measures through the sagittal plane and solely provides information in relation to the knee positioning through the motion of flexion and extension. It seems significant to analyse and measure the amount of medial/lateral movement the knee produces on landing from a single leg hop, as these movements have been shown to be a major contributor to serious injury (Levine et al., 2012). These medial/lateral measures are easily obtained through motion/video analysis. Research has been done to establish the movement occurring within the knee post fatigue and these have

been completed in open and closed kinetic chain exercises (Riberio et al., 2010; Thomas et al 2010).

Another functional proprioceptive measure used in sport is the Star Excursion Balance Test (SEBT). This test has been used to gain quantifiable measures of dynamic postural control deficits and used as an indicator for lower limb injuries. Gribble et al., (2012) concluded from their systematic review that 'more than a decade of research findings has established a comprehensive portfolio of validity for the SEBT, and it should be considered a highly representative, non-instrumented dynamic balance test for physically active individuals. The SEBT has been shown to be a reliable measure and has validity as a dynamic test to predict risk of lower extremity injury, to identify dynamic balance deficits in patients with a variety of lower extremity conditions, and to be responsive to training programs in both healthy individuals with injuries to the lower extremity (Gribble et al., 2012). Clinicians and researchers should be confident in employing the SEBT as a lower extremity functional test'. This is a simple test to administer and guidelines include that pre testing athletes should be allowed between 4 – 6 trials to familiarise themselves with the test, any more than this would cause a practice effect and thus would reduce the reliability of the results (Hertel et al., 2000; Robinson et al., 2008). The protocol for this test is simple the star is set out on the floor and participants are asked to stand on one leg, with their foot flat to the floor. They are then asked to reach with the other foot as far out down the requested lines as far as they can. This distance is then measured and graded (Gribble et al., 2012). The SEBT has been utilised in all of the above research as a measure of proprioceptive ability. Clearly, function of the mechanoreceptors and physiological proprioceptive responses will contribute to the maintenance of balance when performing, but it is important to note that this is a measure of the athlete's ability to maintain dynamic stability, on a stable surface where the centre of gravity (COG) is manipulated by movement of the non-stabilising limb. When movement of the non-stabilising limb occurs, it is done within the athlete's comfort zone and in some subjects utilised, question marks exist over how far would they push to their limit. Therefore, questioning how functional this dynamic stability test is. It is also important to acknowledge that by maintaining a controlled position and allowing movement to be performed at the athletes own pace provides them with the opportunity to steady themselves before initiating the reach of the non-stabilising limb.



Another test that could be utilised to measure dynamic stability within athletes is the Biodex Stability System (BSS). Various researchers have utilised the BSS to determine the level of the subject's proprioceptive response within the knee (Wikstrom et al., 2006; Moezy et al., 2008; Vathrakokilis et al., 2008; Al-Dadah 2011; Gioftsidou et al., 2012; Jureviciene et al., 2012; Torres et al., 2012) Throughout all of these papers what has actually been determined is the subject's ability to maintain dynamic balance. In contrast to the SEBT the BSS gives a measure in relation to the degree of tilt not a measure based on deviation from the centre of pressure (Arnold et al., 1998). It is important to note that research utilising this equipment has again made generalisations to the populations tested and their proprioceptive function. It is clear from the data and output given from a measure on the BSS that we can draw assumptions on the athlete's proprioceptive abilities, but in reality, we are achieving an effective outcome measure, which is a score to determine whether the athlete can maintain dynamic balance/stability. The major advantage of this testing procedure over the SEBT is that the tilt of the plate, the athlete is stabilising themselves on, is uncontrollable by the subject and the degree of tilt is set in relation to the testing procedure. This provides the athlete with the challenge of maintaining dynamic stability/balance, unpredictably on an uncontrollable surface. Due to the nature of proprioceptive function being mainly unconscious and the multi factorial nature of the receptors within skin, joints and muscle tissue any slight deviation on the platform will cause it to tilt and an immediate adjustment is required to regain stability/balance. The BSS has been utilised to measure how exhaustive eccentric loading effects dynamic stabilisation post event (Melnyk et al., 2007; Letafatkar et al., 2009; Thomas et al., 2010; Millet 2011; Changela et al., 2012; Hassanlouei et al., 2012). Similarly, like research focussed on eccentric strength it has been analysed alone and the temporal pattern post fatigue has not been researched. These measures have been completed immediately post event and not tracked over a period of time post event, to investigate the length of time the eccentric loading effects dynamic stability. It is suggested that eccentric loading affects the intrafusal fibres of spindle muscles and tendon organs (Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). Indicating that dynamic stability used to quantify muscle function post eccentric loading could be a useful measure, due to its significance in preventative and rehabilitative programs.

Scores achieved on the BSS are through two planes anterior-posterior (A-P) and medial-lateral (M-L) and this provides an overall stability score (OSI). The hamstring muscle is a vital muscle group that provides stability to the knee due to its multi-function it controls medial and lateral

rotation of the tibia and when in a closed kinetic position, controls anterior translation of the tibia when performing functional movements. The hamstring is required to have good eccentric strength to be able to maintain stability, but also reduce load on the ACL. Consequently, suggesting that dynamic stability accompanied with eccentric strength could be two key combined markers when trying to determine pre cursors of injury, especially as it is now commonly accepted that aetiological contributors to injury are multi factorial (Opar et al., 2012).

Reliability and validity of the BSS has been questioned in research and it has been highlighted that it would not be recommended as a gold standard piece of equipment for measurement of stability (Pickerill et al., 2011). Pickerill et al., 2011 completed with a healthy population (n = 23). There was also no indication that these people were sporting athletes and neither was it indicated whether each subject had used the BSS prior to being tested. The major flaw within this study was the methods used. The subjects were not familiarised prior to the test day and were provided the opportunity to 'practice' on the BSS 3 minutes before the testing procedure was initiated, also presenting question marks with regards a potential fatigue effect. The flaws in this research present justification for not discounting the BSS as a measure of dynamic stability. It is clear that to maintain good dynamic stabilisation and reduce anterior translation within the knee then there will be a requirement within the hamstring muscle to maintain good functional strength. If this is compromised as a result of fatigue, then the dynamic stabilisation will be unable to be maintained and the knee will be vulnerable to stresses related to ACL injury. To further current research in this area analysing the temporal pattern post fatigue accompanied with measures of eccentric strength, will allow comparisons to be made between the two and to identify if the recovery rates are similar in each factor associated with injury. If they differ then suggestions will be able to be made with regards preventative strategies of when to focus on certain components within training protocols. The nature of the testing procedure on the BSS provides athletes with increased challenge due to the unpredictability of the unstable platform and the requirement to adjust and elicit an effected response within the musculature to hold position and stabilise body position, not allowing the knee to fall in to a high-risk movement pattern.

The research discussed highlights a potential correlation between reductions in eccentric strength and dynamic stability as a result of fatigue. Conclusions drawn from the literature discussed surrounding eccentric strength and dynamic stability has predominantly highlighted

the acute effects of fatigue. As a result of game play or repetitive bouts of eccentric loading, post the immediate acute effects of exercise players would be subjected to Delayed Onset Muscle Soreness (DOMS) (Ernst., 1998; Cheung et al., 2003; Connolley et al., 2003; Micklewright., 2009; Nelson., 2013). To combat or prevent the DOMS effect post exercise, clubs and players typically implement their own recovery strategies as an intervention measure post game play to try to accelerate recovery. Having identified the modifiable and quantifiable aetiological factors associated with hamstring and ACL injuries the final stage of the intervention process is applying effective intervention strategies.

## **2.6 Interventions:**

### **2.6.1 Current Interventions:**

Typically, intervention strategies have been presented in research as multi-modal (Ekstrand et al., 1983) and then further developed in more current research (Van Mechelen Model 1992; Finch., 2006; Van Tiggelen et al., 2008; Verhagen et al., 2010). All of these strategies have failed to result in a decrease in injury incidence in the last decade and research indicates that these hamstring and ACL injuries are actually on the rise (Bjordal et al., 1997; Woods et al., 2004; Fauno et al., 2006; Arnason et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012). In relation to ACL injuries it is also important to note that more recent evidence has indicated that 65% of professional football players fail to return to the same level post injury (Walden et al., 2016). This emphasises the need to further analyse the temporal pattern of fatigue post event and look at where common intervention strategies that are utilised within football are best implemented and when applied do they then affect the temporal recovery.

Numerous intervention strategies have been researched and implemented within soccer in an attempt to decrease the incidence of hamstring and ACL injuries. These interventions have been heavily focussed on decreasing the effects of fatigue post event by accelerating the recovery process (Davies et al., 2009; Gallaher et al., 2010; Duffield et al., 2010; Burgess., 2010; Lovell et al., 2011; Hill et al., 2013; Fonda et al., 2013; Pruscino et al., 2013; Hill et al., 2014; Hohenauer et al., 2015; Ferreira-Junior et al., 2015; Marques-Jimenez et al., 2016) and also by applying training interventions to decrease the effects of the aetiological factors associated with injury (Sayers et al., 2008; Petersen et al., 2011; Daneshjoo et al., 2012; Opar

et al., 2014; Barengo et al., 2014; Van Der Horst et al., 2015; Bahr et al., 2015; Marshall et al., 2015; Barengo et al., 2015; Whitaker et al., 2015).

Two common practices utilised within sport are the application of compression garments post event to catalyse the physiological processes to accelerate recovery post fatigue (Davies et al., 2009; Gallaher et al., 2010; Duffield et al., 2010; Pruscino et al., 2013; Hill et al., 2014; Marques-Jimenez et al., 2016). The use of ice baths or cryotherapy chambers have also been implemented (Burgess., 2010; Fonda et al., 2013; Hohenauer et al., 2015; Ferreira-Junior et al., 2015). Research in this area has shown that the perceived benefits of these strategies outweigh the improvement or acceleration of physiological or biomechanical function in relation to fatigue and recovery post event.

Training interventions to address the aetiological factors commonly associated with ACL and hamstring injuries have been focused on improvements of functional strength (Sayers et al., 2008; Petersen et al., 2011; Bahr et al., 2015; Van Der Horst et al., 2015;) or implementing a multi modal approach to reducing injury, which incorporates exercises that improve dynamic stability and strength (Daneshjoo et al., 2012; Barengo et al., 2014; Barengo et al., 2015; Whitaker et al., 2015). Predominantly training intervention strategies have focused heavily on Nordic hamstring strengthening and have shown that utilising these training protocols has resulted in a decrease in injury incidence (Sayers et al., 2008; Petersen et al., 2011; Opar et al., 2014; Van Der Horst et al., 2015; Bahr et al., 2015). Interestingly Marshall et al., (2015) has shown that the performance of 5 repetitions of nordic hamstring exercises in players can result in a significant fatigue effect, that may actual increase a player's susceptibility to injury. This is an important consideration as clearly the key to whether these exercises are effective preventative strategies is when these are performed and understanding the temporal pattern of player's post fatigue is a key piece of information in this process. The FIFA11+ and the Harmoknee protocols are another approach utilised within football to increase functional strength and dynamic stability. Although the findings within these areas are mixed to whether they are beneficial, but this may be because the majority of research in this area has been completed on female players (Daneshjoo et al., 2012; Daneshjoo et al., 2013; Barengo et al., 2014; Whitaker et al., 2014; Whitaker et al., 2015).

Fatigue is indicated as a main aetiological factor that is associated with injury, which is a non-modifiable and an unavoidable risk factor, as it is attributed to every game and training session

players partake in. Thus, increasing the importance of understanding the effects of fatigue. All of the above listed evidence highlights intervention strategies utilised within football and as stated they have unsuccessfully reduced hamstring or ACL injuries in football (Hawkins et al., 1999; Hawkins et al., 2001; Orchard et al., 2001; Renstrom et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Hewett et al., 2013; Ekstrand et al., 2016). Potentially there are two approaches to analyse in relation to intervention strategies; 1) applying a therapeutic intervention to promote and catalyse the recovery process at the point, post fatigue, when least recovery occurs and 2) reducing the playing time to see if this has an effect on the temporal pattern post fatigue. It is commonplace in sports to utilise interchange rules to reduce the playing time for players, which are utilised to reduce the demands of game play on athletes, but also for tactical advantage. Soft tissue massage represents a recovery intervention strategy that happens throughout all levels of football, but inconsistencies of when it is applied, how it is applied and who applies the therapeutic strategies currently exist.

### ***2.6.2 Soft Tissue Massage:***

A common therapeutic intervention used to aid recovery across all sports; with its use being well documented in football, is soft tissue massage. Research relating to the use and effectiveness of soft tissue massage is contradictory and there are inconsistencies with regards the optimal time of use within literature (Cafarelli 1990; Tidus et al., 1995; Shoemaker et al., 1997; Ernst., 1998; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). Commonly across all of these papers the researchers identify that the evidence to support or refute the use of sports massage as a tool for recovery post sports performance. They all suggest the need for further research, identifying the need to highlight the optimal time scale for implementation post recovery. Potential suggestions for why these inconsistencies are apparent in current literature could be attributed to the lack of understanding of when to implement these therapeutic interventions, who is implementing these techniques and also how the massage is applied. Analysing the methodologies of all of the above literature indicates a lack of clarification of these points, which are crucial and until these are addressed conclusions cannot be drawn to whether or not sports massage is an effective recovery tool.

A common massage technique utilised in a recovery sports massage post event is effleurage. This technique is identified as maximising blood flow to the stimulated muscular area; thus indicating that an increased blood flow would encourage the removal of fatiguing bi-products within the muscle post event. Portillo-Soto et al., (2014) concluded that soft tissue mobilisation and massage therapy increased blood flow. They attributed this increased blood flow with an increased skin temperature. Massage therapy was applied to 28 participants and measures of skin temperature were taken every 5-min post massage for a period of 60 min. The skin temperature was then compared to the contralateral limb. It was found that the skin temperature was at a peak level at 25 min post exercise, suggesting that blood flow continued to the muscle post the massage-taking place. This said, it is important to note that attributing the increased skin temperature to increased blood flow to the muscle only allows us to make assumptions that the blood flow is increased throughout the tissue and a more detailed investigation would be required to identify if the deeper tissues are experiencing this increase. If a superficial technique is applied, then the hands will be moving across the skin and this would encourage an increased flow at skin level. This does not necessarily mean that the deeper tissues that require an increased blood flow post event would be experiencing this same increased flow (Petrosky et al., 2016). In contrast research has shown clear indications that an increased blood flow at skin level has a positive correlation with increased blood flow in to muscle tissue. This emphasises that the effectiveness of the massage is critically important as it ensures that an appropriate and effective depth is applied (Petrofsky et al., 2008; Tew et al., 2010; Mori et al., 2014; Caldwell et al., 2016). Increased effectiveness of the massage applied and the subsequent increase in blood flow would provide the muscles with the nutrients and oxygen required to aid recovery post event. It is identified that there needs to be further research developed to identify when this massage needs to be applied post event to best facilitate the recovery process.

Best et al., (2008) concludes that case studies produced in research provide little support for soft tissue massage as a recovery tool, but when reviewing randomised control trials there was more evidence that suggested that it is an effective strategy employed post event (Rinder et al., 1995; Gupta et al., 1996; Farr et al., 2002; Robertson et al., 2004; Moraska., 2007). Their review of the current literature identifies the need for more ‘standardised protocols measuring similar outcome variables to conclusively determine the efficacy of sports massage and the optimal strategy for its implementation to enhance recovery following intense exercise.’ There are also question marks within the literature reviewed in this paper to the experience and skills of the researchers applying the massage to the subjects and also when was best to apply the

massage post fatigue. It is important to ensure that the individual who applies the massage has extensive experience in the field and a current practitioner. Evidence suggests that there are physiological effects that occur as a result of sports massage within the tissue (Goats., 1994; Tidus et al., 1995; Shoemaker et al., 1997; Tidus., 1999; Hemmings., 2001; Ogai et al., 2008). The justification for its use as a recovery tool in football is based on the theory, that if blood flow is increased as a result of massage then this will be beneficial in the removal of waste post event. The increased oxygen and nutrients provided to the tissue, as a result of increased blood flow would be advantageous. This therefore stimulates the question when is the best time to implement this massage post event to optimise recovery?

### ***2.6.3 Interchange:***

Rugby league and Australian Rules Football (ARF) have adopted an interchange rule within their game (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Sirotic et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013; Waldron et al., 2013; Black et al., 2013). This rule allows players to be removed from the field of play and then be reintroduced at another point in the game. Coaches and medical teams now monitor their players stringently with global positioning system (GPS) technology and notational analysis devices, which are predominantly used to monitor performance to allow judgements to be made on the individual player's physical state. This can then indicate to the staff when a player should be withdrawn from the game to rest. Evidence has shown that since the introduction of the interchange ruling there has been a positive influence on non-contact musculoskeletal injury (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013) and also a reduction of the acute physiological effects of fatigue (Sirotic et al., 2011; Waldron et al., 2013). This said, there is no evidence to suggest how this interchange influences the temporal pattern of recovery of player's post game play and this interchange research has not been implemented within soccer.

Orchard et al., (2011), investigated the effects of the introduction of interchanges on hamstring injury in ARF. They analysed 56,320 games in ARF over a 7-year period and concluded that regular interchanges resulted in a significant decrease in hamstring strain injuries when players were exposed to regular interchanges. Those players that completed the full game without interchange or a succession of games without interchange were at an increased risk of sustaining injury. They attributed this with the ability to rest a player when fatigued, allowing

them to return to game play post recovery. To be classed as being exposed to regular interchanges players must have been exposed to 7 interchanges or more in 3 weeks. These findings were supported by conclusions drawn in an earlier study by Gabbett (2005), who analysed the effect of interchange on rugby league players. The research concluded that the players who were exposed to interchange significantly reduced their chances of injury.

Although the demands of rugby and ARF are different to those of soccer the positive influence that the interchange rule has had on non-contact musculoskeletal injuries cannot be ignored. Taking in to consideration the success of this rule change in rugby league and ARF it seems logical to suggest that a similar rule change implemented in to football could potentially have the same effect. In addition, analysis post fatigue and the subsequent temporal pattern would not only identify the acute effects of fatigue, but also develop an understanding how this approach effects the function of players 72 hours post event. To date there is no research currently that has investigated the effects of interchange on injury markers in football. Suggesting it would be beneficial to assess the effects of interchange within game specific fatigue on biomechanical function and how interchange alters the temporal pattern of player's post game play.

## **2.7 Overall Summary:**

It is evident from the research discussed throughout the literature review that the most appropriate and significant measures of muscle function are dynamic stability and eccentric muscle strength. These variables will be used throughout the studies within the thesis, as they have been clearly linked to injury. It is important to note that literature has identified that the reasons attributed to injury are multi factorial (Engbretsen et al., 2010; Goldman et al., 2011; Mendiguchia et al., 2012; Opar et al., 2012; Ekstrand et al., 2016). Even though dynamic stability and eccentric strength have been identified as the main pre cursors of injury the temporal pattern post fatigue has not been tracked and the implications and potential effects of the level of these biomechanical measures 72 hours post fatigue needs to be established. Tracking the temporal pattern simultaneously will allow identification of where potential interventions would be best applied to accelerate this recovery post event. Eccentric strength (Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011) and dynamic stability (Hiemstra et al., 2001; Ribeiro et al., 2008; Torres et al., 2010; Ribeiro et al., 2010; Changela et al., 2012)



of the athlete have both been shown to decrease as a result of fatigue. Establishing the temporal pattern of each of these biomechanical markers post fatigue will allow comparisons to be made between the two. It will indicate if the two systems recover in a parallel manner or at different rates, which would have implications on intervention strategies and resultant training protocols.

Aetiological and epidemiological markers of hamstring and ACL injuries have been well established through research (Bjordal et al., 1997; Woods et al., 2004; Fauno et al., 2006; Arnason et al., 2008; Aletorn-Geli et al., 2009; Engebretsen et al., 2010; Anastasi et al., 2011; Walden et al., 2011; Mendiguchia et al., 2012; Serpell et al., 2012), but knowledge of these markers and various interventions applied have not seen a reduction in occurrence of these injuries (Bjordal et al., 1997; Woods et al., 2004; Fauno et al., 2006; Arnason et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012). Recent evidence indicates a rise (Ekstrand et al., 2016) and a failure to return all athletes to the previous level of play post ACL (Walden et al., 2016). It is evident due to basic functional anatomy that the hamstring muscles have an integral role in providing stability through the knee joint and reducing loads exerted on the ACL during functional performance. The extent of the hamstrings contribution to stability of the knee requires further analysis and isolation of the hamstring muscle group within a fatigue protocol would provide key information to its contribution to stability of the knee and how reductions of eccentric strength affect this. Other factors affecting the ability of the hamstring to stabilise the knee could be due to the impairment of the afferent/efferent pathway as a result of fatigue (Ristanis., 2009; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015) or the reduced number of mechanoreceptors detected within the ACL (Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009). A reduction in mechanoreceptor composition cannot be altered and may contribute to the efficiency of the neuromuscular response. By controlling the effects of fatigue and potentially modifying them and developing a more detailed view of the temporal pattern post fatigue, will allow sports science, medical and coaching staff to manage players more efficiently.

Fatigue has been successfully quantified within research and identified as a key aetiological factor contributing to injury, due to the association with reductions in eccentric strength (Pincivero et al., 2000; Willems et al., 2002; Koller et al., 2006; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011) and dynamic stability (Ribeiro et al., 2008; Torres et al., 2010;

Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). Game time has not been modified to analyse whether the effects of fatigue can be reduced, which is a strategy that has been successfully implemented within other sports (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Sirotic et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013; Waldron et al., 2013; Black et al., 2013). Alternatively, if the effect of fatigue cannot be reduced with an intervention of interchanging players then alternative recovery strategies need to be analysed. Sports massage has been shown to have various physiological benefits (Goats., 1994; Tidus et al., 1995; Shoemaker et al., 1997; Tidus., 1999; Hemmings., 2001; Ogai et al., 2008) if applied by a clinician of appropriate experience. It seems clear that the evidence presented in sports massage and the effects on recovery have been in relation to the acute effects of fatigue and applied immediately post event (Rinder et al., 1995; Gupta et al., 1996; Farr et al., 2002; Robertson et al., 2004; Moraska., 2007). Determining the temporal pattern of key aetiological biomechanical markers like eccentric strength and dynamic stability would highlight the most appropriate time to apply the massage and determine any effect on the temporal pattern post event.

Knowledge of aetiological biomechanical markers that contribute to injury can be utilised to guide the rehabilitation process and can identify key markers to be used to successfully return the athlete to play post injury. Recent research has shown that 35% of professional footballers do not return to the same level of play post ACL (Walden et al., 2016). Potentially highlighting the need for key markers to be identified, particularly in the later stages of rehabilitation when analysing players fatigue resistance. Deeper understanding of a temporal pattern could potentially highlight the players readiness to return, as well as informing preventative strategies for individual players. These markers could possibly be used to prevent any recurrence of injury (Van Mechelen Model 1992; Finch., 2006; Van Tiggelen et al., 2008; Verhagen et al., 2010), which is commonly seen in ACL ruptures (Myer et al., 2012; Shelbourne et al., 2013; Hewett et al., 2013). Myer et al., (2012). Shelbourne et al., (2013) identified that post ACL reconstruction functional deficits existed within athletes right through the rehabilitation process; thus, emphasising the need to have quantifiable measures that would guide the rehabilitation post injury and progression through the various stages to return to play. These markers could then also be utilised to monitor the player's susceptibility to reoccurrence of injury, when they become more functional and utilised within their return to play criteria Hewett et al., (2013).

## **Chapter 3: General Methodology**

### **3.1 Introduction:**

Evidence has shown the negative impact that non-contact musculoskeletal injuries sustained by players have on football club's performance due to days missed and the financial implications associated with them (Woods et al., 2002; Orchard et al., 2009; Rahnama et al., 2009; Fisher et al., 2011; Yoon et al., 2011). Decreased eccentric hamstrings strength and dynamic stability have been highlighted as two main contributory factors to lower limb non-contact musculoskeletal injuries such as; hamstring strains and ACL strains/ruptures (Opar et al., 2012). Evidence also highlights that soccer fatigue causes a decrease in dynamic stabilisation and eccentric hamstrings function due to the high eccentric loads experienced in game play (Greig 2008; Small et al., 2009; Thomas et al., 2010; Gioftsidou et al., 2011; Changela et al., 2012).

As discussed in the previous chapter, there are various means of measurement that can be utilised to quantify these measures of muscle function. The most reliable and valid measure of quantifying eccentric hamstrings strength is the IKD (Steiner et al., 1993; Gaines et al 1999; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Cesar et al., 2013; Ribeiro et al., 2015). Measurement of dynamic stability has been completed via a myriad of laboratory and field based tests including the SEBT, Single Leg Stand and Single Leg Squat (Wikstrom et al., 2006; Moezy et al., 2008; Vathrakokilis et al., 2008; Riberio et al., 2010; Thomas et al 2010; Al-Dadah 2011; Gioftsidou et al., 2012; Jureviciene et al., 2012; Levine et al., 2012; Gribble et al., 2012). The most quantifiable measure of dynamic stability is through measurement of OSI, A-P, and M-L utilising the BSS (Pickerill et al., 2011; Torres et al., 2012; Yamada et al., 2012). The IKD and BSS are therefore utilised throughout the thesis studies to quantify neuromuscular function and dynamic stabilisation respectively. The studies will utilise these measures to monitor temporal patterns post localised and soccer specific fatigue; to analyse the effects of interventions of interchange and sports massage on temporal patterns post fatigue; and to determine muscle function post ACL semitendinosus autograft in a professional footballer.

### **3.2 Participants:**

Sixty-nine professional footballers were recruited across all studies contained within the thesis with a mean age  $23.04 \pm 4.54$  years, height  $184.21 \pm 4.85$  cm and body mass  $76.14 \pm 5.76$  kg. All participants were given clear guidance of the procedures of each study and these were clearly explained before any ethical approval was obtained. Participants attended the laboratory following a 72-hour abstinence from vigorous exercise and alcohol. All participants were asked to ensure they were appropriately hydrated with water leading up to testing and had not eaten 3 hr prior to testing.

Given the nature of the experimental design, players were asked to complete a training diary throughout the period of the study. This diary was described in detail to each player individually, and completed in liaison with their host club. This training diary briefly documented the date, time, nature and duration of all physical activity. The diary was used to facilitate control over activities undertaken between testing sessions, and also to ascertain current training status prior to experimental studies commencing. Where activity between trials was deemed to potentially influence performance during the experimental trial, the study was ceased for that participant.

#### **3.2.1 *Sample Size:***

*A priori* power calculations was conducted using familiarisation trials and pilot data completed by participants matching the criteria described above. Across all isokinetic and stabilometry measures considered within the thesis, a sample size of  $\geq 14$  players was required to evaluate the interactions associated with all independent variables (for statistical power  $> 0.8$ ;  $P < 0.05$ ). Given the recruitment of the players and their engagement with the testing, 14 was therefore set as a minimum requirement although greater numbers were considered to enhance the power of the study without compromising ethical considerations.

### ***3.2.2 Ethical Considerations:***

Ethical approval for each study within the thesis was granted by Edge Hill University's Ethics Committee (SPA-REC-2014-334) and adhered to the guidelines outlined in the university's Research Ethics Framework (2007), British Association of Sport and Exercise Science Testing Guidelines (2007) and in accordance with the Helsinki Declaration.

Prior to the completion of any physical testing participants were informed of the following; all procedures, the nature of the studies, their rights as participants and any risks and discomforts associated with these studies. Following this, the participants were required to complete written informed consent to acknowledge that they understood the information provided and consented to participation within the relevant research. Participants had the right to withdraw from the study at any time.

The risks involved in completing any of the studies for a healthy person were those associated with high intensity exercise i.e. musculoskeletal injury or a cardiac event. All testing was completed indoors in a laboratory-controlled environment on the IKD and the BSS with only the participant and the researcher present.

General health and safety procedures were followed as detailed in Edge Hill University's department health and safety manual. Due to the testing involving strenuous exercise, suitable screening was carried out involving risk stratification, and resting measurements; for this the participant had blood pressure, heart rate, weight and height measured to determine resting values, but also to ascertain if they were healthy enough to participate in the subsequent testing. A comprehensive pre-exercise questionnaire was also completed; this consisted of the completion of a number of questions to determine if there were any other factors that may have prevented the participant from participating in the testing.

All researchers were appropriately trained with all equipment and are also qualified first aiders. Constant communication was also maintained between the participant and the researcher and both heart rate and rating of perceived exertion (Borg Scale., 1970) were measured to monitor the participant's health and ability to exercise during each trial.

Following the completion of the written informed consent, the participants were allocated a unique ID number. This number in turn was then used to identify the participants on all other documentation excluding the consent form. Participants were given the right to withdraw their data within four weeks of the completion of the final testing sessions by providing their unique ID number (the researchers details were provided following the completion of the written informed consent form).

It must be recognised that the participants consent forms were stored separately from the other data collected and following the completion of the informed consent the unique ID number was the only method used to identify the participants. Although all data was coded using these ID numbers, the data sets were stored on a password protected mass storage device and PC in line with the Data Protection Act (1998).

### ***3.2.3 Inclusion/Exclusion Criteria:***

All participants were required to be playing at a professional standard of football. A professional footballer is defined as an individual, 'who has a written contract with a club and is paid more for his footballing activity than the expenses he effectively incurs' (FIFA., 2003). It was appreciated that training schedules of clubs varied week to week, but it was established that all participants in this study trained a minimum of 4 times per week and had at least 1 game per week, in a normal schedule. Any players who had a history of cardiovascular diseases, diabetes, hypertension or who had sustained a lower limb musculoskeletal injury in the last 6 months were excluded from participation in studies 1 - 4 (Chapters 4 – 7). Pre exercise measures were taken, which included anthropometrics, heart rate, blood pressure and familiarisation trials on the testing and fatigue protocols, to ascertain if players were capable of meeting the demands of the testing procedures. If players could not complete the tests, for example they could not match the isokinetic speeds of the IKD, then they were excluded from the study.

### ***3.2.4 Pilot Study:***

Confirmation of the final experimental design was only made once the relevant pilot work had been completed. Due to the participants recruited for the study all being elite footballers they had all, at some stage within their careers, completed testing on the IKD and BSS. Further

consideration was given to the position in which the athlete was tested within the IKD, to replicate a more functional position than the traditional method used of testing the participant in an upright-seated position. IKD assessment of the functional strength of the hamstrings can also be completed in standing. One participant performed testing in supine and in standing and it was identified that the torque values exhibited were considerably less in supine. Supine testing was completed due to its replication of hip flexion and knee extension, which is a mechanism of injury commonly associated with sustaining hamstring injury (Guex et al., 2012).

On discussion with the participant completing the pilot they explained that they felt when supine that the hamstrings felt stretched and they could not generate the same resistance against the eccentric work than when seated. It was hypothesised that this position potentially placed the sciatic nerve on stretch, as it replicated a straight leg raise position where the athlete was placed in hip flexion and knee extension. This resulted in the athlete not being able to generate enough force when trying to perform the resultant contraction. To try to reduce this stretch the lever range of the dynamometer was adjusted, and the ROM decreased. However, this neutralised the hip flexion and brought them in to a position that replicated the testing in seating. Due to the difficulties experienced of trying to replicate a more functional position of hip flexion and knee extension and the need to isolate the hamstrings to establish the functional strength of the hamstrings it was decided to complete the IKD testing in the traditional seated position. When seated and in flexion it was identified that some participants could not generate the force needed to initiate the IKD. This happened on repeated tests and made the torque outputs inconsistent. It was decided to reduce full flexion by  $5^{\circ}$ , on doing this all participants could consistently generate the required force and torque output became consistent within sets.

Study 1 in Chapter 4 required the development of a localised fatigue protocol on the IKD. The fatigue protocol was designed for the participants to complete consecutive sets of 15 repetitions until their  $PkT_{ecc}$  reduced by 30%, consistent with the reductions exhibited within match specific fatigue protocols (Greig., 2008 and Small et al., 2009). Initially, these repeated isokinetic repetitions were completed at  $150^{\circ} s^{-1}$ . It took the first participant 35 minutes to elicit a 30% drop in two consecutive repetitions, but then they recovered and could perform the 3<sup>rd</sup> repetition with only an 18% reduction in  $PkT_{ecc}$ . This then continued, so the testing was postponed. The pilot was then completed on a second subject, who exhibited a similar response. The decision was then taken to increase the isokinetic speed to  $300^{\circ} s^{-1}$ . When fatigued at this speed participants demonstrated that once that had hit the initial drop of 30%

PkT<sub>ecc</sub>, they did not recover. The faster speed better replicates the mechanism of injury within hamstring and ACL injuries, as these are more commonly sustained at high velocity (Bollen 2000; Arnason et al., 2008; Engebretsen et al., 2010).

Pilot testing on the BSS was also completed. Stability testing levels vary across literature, but commonly range from level 1 to 4 (Pickerill et al., 2011; Torres et al., 2012; Yamada et al., 2012). In the pilot study the subject initially attempted testing at level 4. When completed the participant exhibited very little instability and it was clear there was no challenge to maintain their single leg balance. Literature has indicated that elite athletes should be tested on level 1 of the BSS, as it replicates greater challenge (Yamada et al., 2012). The nature of football performance also provides justification for a more unstable level, as they perform on grass in football boots, each creating an unstable surface to perform on. Within the pilot the subject also completed testing with and without appropriate training shoes. It was identified that the training shoe provided more stability and results were significantly better, as a result of performing in the training shoe. Footwear has been shown to alter the kinematics and muscle activity within the lower limb and this changes as a result of different types of footwear (Franklin et al., 2015). This promotes challenge of any testing or training completed on footballers, as they predominantly perform in football boots. Unfortunately, boots could not be worn on the BSS, so it was decided to remove all footwear so that the 'true' dynamic stability of the athlete could be determined. As a result of the findings in the pilot study, it was decided to complete the BSS testing on level 1.

Finally, field tests were given considerable consideration. These included completing the soccer specific fatigue protocol on the grass and carrying out a SEBT test for dynamic stability on the grass and in football boots. It was decided that there were too many variables that could not remain consistent throughout the four studies within the thesis to keep testing consistent, particularly when performing SEBT in the field. An example of this would be adverse weather conditions could alter the playing surface and this could create a more unstable surface. Difficulty and delay would have also been encountered when trying to perform the IKD assessment, as this piece of kit was not transferrable. Emphasis within the studies contained in the thesis was on isolated hamstrings strength measures and the IKD measures have been shown to be the most appropriate method. Consideration of all these factors, accompanied by the knowledge that elite football clubs commonly utilise the IKD and BSS in screening of their athletes, led to the decision that all testing would be completed in an ambient temperature



controlled laboratory.

### **3.3 Experimental Design:**

Prior to any familiarisation or testing within the experimental studies each player's height and weight measures were taken. The height of each participant was measured in centimetres, to the nearest millimetre, using the Seca Road Rod Stadiometer 214. The stadiometer was assembled and placed on a flat floor next to a wall to ensure it was kept up straight. Participants were required to remove their shoes prior to measurement, and stand neutrally facing forward. Post obtaining height measures the weight of each participant were then taken. Weight was measured in kilograms to the nearest 0.1kg, using the Seca 761 flat mechanical scales. The scales were calibrated to 0kg and were placed on a flat floor. Again all participants were required to remove their shoes prior to measuring.

Participants were required to attend the ambient temperature controlled laboratory to complete a familiarisation trial on the IKD and the BSS to negate potential learning effects (Hinman., 2000). Each of the trials were completed on the dominant lower limb identified by their favoured kicking foot, as research has indicated this is a pre cursor of ACL injury in male athletes (Brophy et al., 2010). Each player identified their favoured kicking foot and this was noted as the dominant limb. All participants involved in the studies completed all testing between 13:00 and 17:00 hrs to account for the effects of circadian rhythm (Drust et al., 2005; Nicolas et al., 2008; Bougard et al., 2010; Sedliak et al., 2011) and in accordance with regular training and competition times. Familiarisation of the testing equipment was completed in one session, 7 days prior to testing beginning. The familiarisation trials were consistent with the testing procedure completed in the studies. The participants completed testing procedures on the IKD at the varying testing speeds ( $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ), similarly participants were subjected to 3 trials on level 1 of the BSS, so they were aware of expectations when testing began. Some participants were required to complete more than one familiarisation trial to ensure that they were completing the task correctly. Verbal encouragement was provided throughout the testing process as this replicated the encouragement they traditionally receive during performance (Enoka., 1992; McNair et al., 1996; Kim et al., 1997; Gandevia 2001; Knicker et al., 2011). The testing period was completed at the beginning of the off-season period. This ensured that during the recovery phase, post fatigue, players refrained from

physical activity or training and maintained their normal nutritional intake, as guided by their clubs. Player's were asked to maintain a normal daily routine post fatigue.

### ***3.3.1 Isokinetic Dynamometry:***

Participants were required to attend for testing in full training kit and athletic trainers that they would wear when completing gym sessions or runs at the club. Data collection on the IKD (System 3, Biodex Medical Systems, Shirley, NY, USA) consisted of 3 x 5 sets of eccentric hamstrings work, which was followed by passive movement back in to knee flexion guided by the IKD at  $10^{\circ}\cdot s^{-1}$ . Participants were seated in the IKD and straps were applied across the chest, pelvis and mid-thigh to minimize extraneous body movements during muscle contractions. The rotational axis of the dynamometer was aligned to the lateral femoral epicondyle and the tibial strap placed distally at three-quarters of the length of the tibia. Participant's arms were positioned across the chest to isolate the hamstrings during torque production (Li et al., 1996; Dauty and Rochcongar, 2001; Hadzic et al., 2010). Figure 3.1 provides a representation of the isokinetic dynamometry set-up.



Figure 3.1. Figure 3.1: Experimental set-up for Isokinetic Dynamometry Testing.

The order each set was completed was randomised (set one at  $150^{\circ}\cdot s^{-1}$ , set two at  $300^{\circ}\cdot s^{-1}$  and set 3 at  $60^{\circ}\cdot s^{-1}$ ). This was to prohibit subjects placing greater emphasis on the final set of

eccentric contractions completed, which was observed during the familiarisation trials and consistent with the findings of Greig., (2008). This is contrary to previous recommendations that propose progression from slow to fast (Wilhite et al., 1992). The measures at each speed show good reliability with ICC's ranging from 0.76 – 0.78 (Greig, 2008). Each participant was told to complete each repetition throughout every set to their maximum and were encouraged to do so throughout with verbal and visual feedback (Enoka., 1992; McNair et al., 1996; Kim et al., 1997; Gandevia 2001; Knicker et al., 2011). This allowed the participants to become familiar with the eccentric work on the IKD, but also exposed them to the varying three speeds that formulated their assessment over the subsequent time points post fatigue.

Before testing was completed in each of the studies, participants completed a familiarisation trial of 3 repetitions on the IKD 7 days pre testing beginning. Each repetition completed eccentrically on the IKD was observed by the researcher and was smooth with consistent effort exerted, which was monitored through the athlete's performance. The seat position and set up of the IKD was subject specific and once comfortable within the IKD the position of the athlete was noted and completed to the exact same specifications throughout the testing period. All subjects were secured in the IKD with accordance to the manufacturers guidelines with the crank axis aligned with the femoral condyle and the collar of the lever arm strapped around the ankle above the malleoli. Further restraints were applied around the chest and the thigh of the dominant leg proximal to the knee joint, so it did not restrict ROM.

Knee range was individually determined for each participant within each of the studies and these metrics were recorded. Any repeated measures taken on the IKD were done consistently utilising the same settings and ROM. When seated and participants were secured in to the IKD they were asked to perform full extension of the knee. Once full extension had been established they were moved passively in to full flexion, from here flexion was reduced by 5°. During pilot testing it was evident that subjects could not initiate the relevant force required to initiate the isokinetic speeds and thus the machine remained fixed in flexion. Adjusting the ROM slightly enabled all participants to initiate the isokinetic test, resulting in torque values through ROM to be attained.

### ***3.3.2 Dynamic Stability:***

Participants were required to attend for testing in full training kit, all testing on the BSS was completed barefoot, due to the effect footwear can have on kinematics of the foot and muscle activity in the lower limb (Franklin et al., 2015). Dynamic stability measures for each study were assessed on the BSS and utilised as a biomechanical marker to determine the effects of fatigue post trials. Again, stability of the dominant leg was measured as completed on the IKD. The BSS (Biodex Medical Systems, Shirley, NY) is an unstable platform that can tilt up to 20° in any direction, with the stability of the platform determined by the level by which it is set ranging from 1 (most unstable) to 12 (most stable) (Schmitz et al., 1998). Research has shown that the most appropriate level for an elite footballer is level 1 (Yamada et al., 2012).

The participants completed 3 trials of 20 seconds on stability level 1, once completed measures were calculated based on the amount of tilt in degrees for OSI, A-P and M-L. A low index score indicated high stability and high score a low level of stability. Players were asked to repeat trials if it was judged they required further familiarisation with the testing equipment. The BSS was setup in accordance with previous literature (Arifin et al., 2014). Before testing on the BSS began the subjects were asked to remove all footwear and socks. They then stood on the platform in full extension with their dominant limb with their foot in the centre of the platform. The feedback screen was set at eye level and the participants were asked to look at the screen, this was set as such to avoid any unwanted head movement and avoid vestibular distraction. Once set the subjects were then asked to adjust their standing foot to a comfortable position, while the marker on the feedback screen maintained a central position, once done and comfortable the platform was locked in to a stable position and the players foot position was recorded. Once recorded the foot position remained consistent through each trial throughout the testing period. In between each trial players were told to weightbear through the contralateral limb to minimise the effect of fatigue when testing. In cases where subjects lost their balance they were told to use the contralateral limb to stabilise themselves by placing it at the back corner of the BSS and were only encouraged to use the handrails if they completely lost balance. Figure 3.2 provides a representation of the testing set-up.



Figure 3.2. Experimental set-up for stabilometry testing.

### ***3.3.3 Exercise Protocols:***

#### ***3.3.3(a) Localised Fatigue:***

On completion of the localised fatigue protocol all participants were required to attend for testing in full training kit and athletic trainers that they would wear when completing gym sessions or runs at the club. It has been identified through soccer specific fatigue protocols that the eccentric hamstrings peak torque reduces between 20-30% post game (Greig., 2008; 2009; Small et al., 2008; Small et al., 2009). Although reductions in eccentric function have been highlighted within these protocols through a variety of testing speeds from slow to fast the isolated effects of fatigue on the hamstrings have not been identified. Completion of a localised fatigue protocol on the dominant limb hamstrings will establish if the temporal effects post fatigue are similar to those elicited from game specific fatigue. Evidence has emphasised the importance of eccentric strength and fatigue resistance in relation to the hamstrings (Askling et al., 2003; Arnason et al., 2008; Mackey et al., 2011; Petersen et al., 2011). By establishing how local fatigue effects the hamstrings it will heighten the importance of building fatigue resistance of the hamstring muscle group through rehabilitation and prehabilitation protocols, in relation to hamstring and ACL injury. This would provide direction specifically post hamstring or ACL injury with guiding and developing return to play protocols.

Each participant completed a succession of eccentric isokinetic contractions at  $300^{\circ}\cdot\text{s}^{-1}$  of the hamstrings on their dominant limb until they achieved a 30% drop in their eccentric hamstrings peak torque (Greig., 2008; Greig et al., 2009; Small et al., 2009) which was calculated from their baseline measurements prior to completion of the localised fatigue protocol. Fast speeds of eccentric torque were selected, as this represented the loadings (Gaines et al., 1999; Drouin et al., 2004; Greig., 2008) and mechanism of injury associated with hamstring (Orchard et al., 1997, Woods et al., 2004, Gabbe et al., 2006, Arnason et al., 2008, Engebretsen et al., 2010, Pizzari et al., 2010, Mackey et al., 2011, Opar et al., 2012, Mendiguchia et al., 2012, Serpell et al., 2012, Ropiak et al., 2012, Orchard et al., 2012, Ekstrand et al., 2016) and ACL injuries (Bjordal et al., 1997, Bollen 2000, Fauno et al., 2006, Yu et al., 2007, Brophy et al., 2010). Continuous repeated sets of 15 repetitions were carried out until a 30% drop in eccentric hamstrings peak torque had been achieved for a succession of 3 consecutive repetitions. Each eccentric repetition was followed by a return speed of  $60^{\circ}\cdot\text{s}^{-1}$  passively in to knee flexion to put the participant in position to complete the next repetition. All participants were secured in the IKD as detailed in section 3.3.1. Prior to the fatigue protocols being taken baseline measures of IKD, at the listed speeds, and BSS were taken. These measures were consistent with methods described in 3.3.1 and 3.3.2 respectively.

### ***3.3.3(b) Soccer Specific Fatigue:***

During completion of the soccer specific fatigue protocol all participants were required to wear full training kit and athletic trainers that they would wear when completing gym sessions or runs at the club. Soccer specific fatigue was delivered through completion of the SAFT<sup>90</sup> soccer specific free running protocol. Before completion of the fatigue protocol, within any of the studies, participants were required to be familiarised with the set up and the timings involved when running the 20 metre drill and attended 7 days prior to testing to complete a 15 min familiarisation trial, if players required longer a further 15 min was repeated (see figure 3).

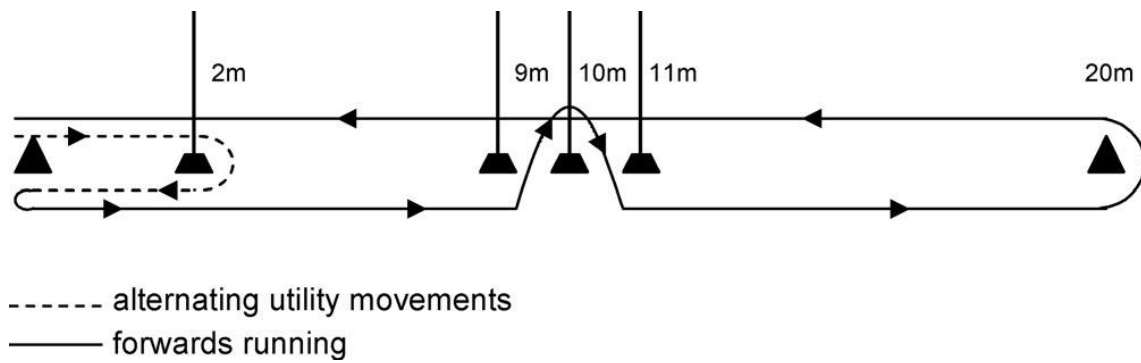


Figure 3.3: A Diagrammatic Representation of the SAFT<sup>90</sup> Field Course (Small et al., 2010)

Small et al., (2009) describes the SAFT<sub>90</sub> protocol as an aerobic field test that consists of 6 x 15 min repetitive cycles. These cycles are completed in sets of 3 and are separated by a 15 min passive rest interval, which replicates half time. Design of the course was designed based on Prozone® level data obtained from Championship playing data in the 2007/2008 season and validated by Lovell et al., (2008). The purpose of the test is to replicate the demands of the modern game and induce soccer specific fatigue within players. It includes multidirectional movement patterns, as highlighted in Figure 3, which replicate movements experienced in the game and also multidirectional loading that has been associated with common non-contact musculoskeletal injuries, such as hamstrings and ACL. The protocol is performed over a 20m course and begins with sidestepping or backwards running around the first pole, 2m from the starting cone. On completion of this the athlete then continues with forward running through the course, working between the 3 poles at 9m, 10m, 11m and through to the 20m, which is navigated around and the player then heads back to the start of the course and repeats. This is all performed to verbal audio cues on a CD and the athlete is asked to respond to these cues accordingly. It is important to note that no kicking or tackling activities are performed throughout the protocol.

<b>Activity</b>	<b>Distance During SAFT<sub>90</sub> (km)</b>	<b>Distance from Match- Play Data (km)</b>
<b>Standing (0.0 km h<sup>-1</sup>)</b>	<b>0</b>	<b>0.02</b>
<b>Walking (5.0 km h<sup>-1</sup>)</b>	<b>3.36</b>	<b>3.60</b>
<b>Jogging (10.3 km h<sup>-1</sup>)</b>	<b>5.58</b>	<b>5.81</b>
<b>Striding (15.0 km h<sup>-1</sup>)</b>	<b>1.50</b>	<b>1.46</b>
<b>Sprinting (<math>\geq 20.4</math> km h<sup>-1</sup>)</b>	<b>0.34</b>	<b>0.27</b>
<b>Total Distance (km)</b>	<b>10.78</b>	<b>11.08</b>

Table 3: Distances Covered of each Activity During the SAFT<sub>90</sub> and Match Play Data (Small et al., 2010)

### **3.4 Data Analysis**

For each study the IKD data was analysed to quantify gravity corrected peak torque measures for the hamstring muscle group when performing eccentric knee extension at 3 speeds ( $150^{\circ}\cdot s^{-1}$ ,  $300^{\circ}\cdot s^{-1}$ ,  $60^{\circ}\cdot s^{-1}$ ). Gravity correction is applied based on the anthropometric measures input in to the Isokinetic Dynamometer when completing the testing. If the correct anthropometric measures are not input on testing the athlete, then a gravity correction is not applied and could potentially affect the reliability and validity of the measures obtained. The IKD is the main testing procedure utilised within research to quantify functional strength of the hamstring muscle group (Gaines et al., 1999; Dauty et al., 2001; Dauty et al., 2003; Drouin et al., 2004; Svennson et al., 2005; Maffiuletti et al., 2007; Impellizzeri et al., 2007; Greig., 2008; Small et al., 2010; Houweling et al., 2010; Findikoglu et al., 2011; Anastasi et al., 2011; Cesar et al., 2013; Riberio et al., 2015). Measures of functional hamstrings strength have been shown to have good-high reliability and validity, when analysing measures at speeds of  $60^{\circ}\cdot s^{-1}$  -  $300^{\circ}\cdot s^{-1}$  (Steiner et al., 1993; Gaines et al 1999; Drouin et al., 2004; Svensson et al., 2005; Impellizzeri et al., 2007; Maffiuletti et al., 2007; Greig., 2008; Cesar et al., 2013; Ribeiro et al., 2015).

Mean PkT, mean AvgPkT and mean <sup>o</sup>PkT values were calculated by identifying two repetitions of similar values with a set of 5 repetitions for each testing speed. Measures of <sup>o</sup>PkT, AvgPkT alongside PkT measures have been shown to increase the functionality of scores exhibited (Svennson et al., 2005, Greig., 2008, Greig et al., 2009, Small et al., 2009). PkT for each



individual within each study was determined by identifying where they could consistently achieve similar torque values, but also replicate this within the same angle through range, which represented the °PkJ. These two reps out of the 5-rep set were then taken and an average value calculated. This was repeated for the angle of peak torque. The average peak torque was then calculated taking the average torque score through the relevant isokinetic phase and then these two values were then averaged against each other. It is important to note that the torque values were only analysed where the participants were meeting the isokinetic testing speeds. On completion of data collection for all subjects within the study an overall average for each measure of Mean PkJ, mean AvgPkJ and mean °PkJ values was calculated. These values were then utilised in statistical analysis for the group.

Throughout the data analysis-testing speeds represented as  $150^{\circ}\cdot\text{s}^{-1}$ ,  $300^{\circ}\cdot\text{s}^{-1}$ ,  $60^{\circ}\cdot\text{s}^{-1}$  with eccentric exercise being represented as ‘ecc’ and hamstrings or knee flexor work indicated with ‘H’. Peak Torque was represented as PkJ, Average Peak Torque as AvgPkJ and Angle of Peak Torque as °PkJ. So for example, average peak torque of the knee flexors at an eccentric speed of  $300^{\circ}\cdot\text{s}^{-1}$  would be AvgPkJ<sub>eccH300o/s<sup>-1</sup></sub>. It is important to note that these values were only taken during the isokinetic phases of eccentric knee extension for each speed tested. Test-retest in professional footballers has been shown to have good reliability, with intraclass co-efficients of 0.76 – 0.78 for the 3 testing speeds utilised (Greig., 2008). Each of these measures were subsequently taken at time points post fatigue.

Dynamic stability scores were ascertained, by use of the BSS, for overall stability indices (OSI), anterior-posterior stability (A-P) and medial-lateral (M-L). Dynamic stability measures of OSI, A-P and M-L were calculated as an average final score from 3 x 20 second bouts on the BSS at level 1. Research has identified that level 1 (most unstable setting) is the most appropriate setting to utilise within elite footballers (Yamada et al., 2012) when analysing dynamic stability. On completion of data collection for all subjects within the study an overall average for each measure of OSI, A-P and M-L was calculated. These values were then utilised in statistical analysis for the group.

Measures of IKD and dynamic stability were then repeated in the subsequent, identified, temporal pattern post fatigue. Timings of when the data was collected were consistent with time points of when post fatigue measures were obtained. This was to factor in the influence of circadian rhythm within measures (Drust et al., 2005; Nicolas et al., 2008; Bougard et al.,

2010; Sedliak et al., 2011). The data for each individual subject was again averaged across the cohort and an overall value for the group within the study was obtained within each identified temporal time point. Overall values for the group for Mean PkT, mean AvgPkT and mean °PkT across identified temporal time points were utilised for statistical analysis. This was repeated for BSS scores across the temporal pattern.

### **3.5 Statistical Analysis:**

The  $PkT_{eccH}$ ,  $AvgPkT_{eccH}$  and  $^{\circ}PkT_{eccH}$  were determined at baseline, and at varying resultant time points post fatigue dependent on the protocol of the study. These measures were also completed at the same time intervals for OSI, A-P and M-L. Initial Q-Q (appendix 1) and box plots (appendix 2 and 3) were completed to determine that the data satisfied normal distribution for all outcome variables within IKD and BSS measures. Potential outliers detected in the boxplots were included in each of the data sets, as they were considered true data representative of sports injury data in elite professional football and thus should be included. Mauchly's test of sphericity was utilised to determine if the variances within the data were equal across the repeated measures design in each study. If the test identified non-significance ( $P \geq 0.05$ ) then sphericity was assumed detailing that the data displayed equal variance. If the test showed significance ( $P \leq 0.05$ ) it would indicate the F value is positively biased and variance between data was not equal. When this was identified the Greenhouse-Geisser correction was utilised. The data was then analysed using a one way repeated measures analysis of variance (ANOVA) for each output measure to establish whether there were significant differences between the base line values and each resultant time point post fatigue, determining if there was a significant main effect for recovery time (appendix 4 and 5). All statistical analysis was performed using PASW Statistics Editor 18.0 for windows (SPSS Inc, Chicago, USA) with an accepted significance level set at  $P \leq 0.05$ .

Additionally, a polynomial function was applied to a regression analysis for IKD ( $AvgPkT_{eccH}$  and  $PkT_{eccH}$ ) and BSS (OSI, A-P and M-L). The strength of the correlation was quantified using the regression coefficient. Differentiation of the quadratic regression curve enabled calculation of the curve minima, and time at which the outcome variable returned to pre-exercise levels.

## **Chapter 4: The Temporal Pattern of Recovery in Eccentric Hamstrings Strength and Dynamic Stability Post-Localised Fatigue**

### **4.1 Introduction:**

Eccentric strength training of the hamstring muscle group is a strategy often used in elite sport, with research indicating that it is a key element implemented within prevention, treatment and rehabilitation programmes to decrease the incidence or recurrence of non-contact musculoskeletal injuries. As medical professionals within sport, accept that these injuries can be a result of a decreased eccentric strength (Askling et al., 2003; Chumanov et al., 2007; Delextrat et al., 2009).

Despite employing this intervention strategy the non-contact musculoskeletal injury occurrence within the hamstrings and knee are on the rise in football (Askling et al., 2003; Agel et al., 2005; Arnason et al., 2008; Rahmana et al., 2009; Engebretson et al., 2010; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Ropiak et al., 2012). It is noted that this approach within research is one-dimensional and amongst clinicians in the field there is an acceptance that the focus requires a multi factorial approach (Opar et al., 2012). The main contributory factors associated with hamstring and knee injuries are eccentric strength, dynamic stability and fatigue (Mair et al., 1996; Koller et al., 2006; Sangnieer et al., 2007; Greig, 2008; Small et al., 2009; Delextrat, 2010; Torres et al., 2010). By analysing the anatomical makeup of the upper thigh it is clear the hamstrings and how they function under fatigue is a key indicator as to why they may be exposed to a strain/tear, particularly in relation to muscular strength (Mair et al., 1996; Small et al., 2008; Greig, 2008; Small et al., 2009; Delextrat, 2010). Consequently, decreases in the eccentric muscular strength of the hamstrings, as a result of fatigue, could potentially result in a decrease in the player's dynamic stability of the knee. Sustaining a reduction in eccentric strength could affect the effector muscles (hamstrings) ability to resist the anterior forces/loads being exerted through functional performance, which would increase the load exerted on the ACL within the knee. Thus, suggesting that eccentric strength deficits as a result of fatigue may not just be a pre cursor for hamstring strains/tears, but also an indicator that the player's chances of sustaining an ACL tear/rupture are also increased.

Commonly the effects of fatigue on eccentric strength and dynamic stability have been analysed as individual components post sport specific protocols and the temporal pattern post fatigue for a succession of days has not been tracked (Mair et al., 1996; Small et al., 2008; Greig, 2008; Small et al., 2009; Delextrat, 2010). Greig et al., (2008) and Small et al., (2009) subjected players to treadmill and free-running protocols respectively and tracked the temporal pattern of eccentric hamstring strength throughout the 90-minute protocols. They both concluded that post fatigue there was a 20 – 30% decrease in eccentric hamstrings peak torque when tested on the IKD at 3 differing speeds, 150<sup>o/s</sup>, 300<sup>o/s</sup> and 60<sup>o/s</sup>. They also highlighted that eccentric strength gradually declines throughout the later stages of each half of the game. Continuation of measures of these deficits in functional strength over a sustained period would detail the strength deficits that take place post fatigue in the lead up to the next bout and outline the pattern of recovery. This is essential information for clinicians, coaches and medical staff, as it will detail a player's readiness in a fixture-congested period or help design subsequent training protocols.

Research has shown that repeated functional movement patterns over time, like those experienced in game play and low angle knee flexion at foot strike result in the quadriceps muscle becoming more dominant and eliciting an increased activation compared to the semitendinosus and semimembranosus muscles (Colby et al., 2000; Pincivero et al., 2000). Due to the functional methodology and the single measures of eccentric hamstrings strength utilised within Greig et al., (2008) and Small et al., (2009) research they were unable to determine whether the hamstring muscle group was becoming less active. They could not differentiate whether this was because of the increased activation and dominance of the quadriceps musculature or if the quadriceps were becoming more dominant and displaying an increased activation because the hamstring had purely fatigued and could no longer elicit the force/control required for performance. Based on this theory it seems logical to assess the effects of fatigue solely on the hamstring muscle group; thus developing the question, what would the effects of a localised fatigue protocol, based on the findings from this research, be on the hamstring function in relation to eccentric strength?

It has been determined that fatigue has a detrimental effect on neuromuscular activity (Rampinini et al., 2011; Robineau et al., 2012) and the link between hamstring strength and dynamic stability is evident, due to the basic functional anatomy. This suggests that it would

be relevant to analyse the effect of localised fatigue on dynamic stability in and eccentric strength of the hamstring muscle group.

Both, components are reliant on a neural innervation to respond to the demands placed on them through performance. Eccentric hamstrings strength is the capacity of the muscle to withstand the force or pressure exerted on it and is elicited as a result of neural innervation to create the appropriate effected output. In contrast, functional dynamic stability is the ability of the neuromuscular system to detect changes through a series of receptors contained in skin, joints and muscle tissue, which can be initiated in game play by abnormal movement patterns or increased loading. These basic definitions highlight the overlap between the two components and how they function, but also emphasise the importance of measuring the two when analysing hamstring fatigue. Clearly, if the hamstring is fatigued and the neuromuscular system is providing a signal to stimulate contraction to resist anterior translation then it may not be able to sustain this due to decreased strength and the ACL will be at risk of being overloaded and damaged. Thus, confirming previous findings in research that decreased hamstrings strength is a key indicator of hamstring and potentially knee injury. Potentially the eccentric strength of the hamstrings could be unaffected by the localised fatigue, but the dynamic stability could decrease. If this occurs, then this would suggest that the mechanoreceptors within the joint or the muscle have been inhibited thus delaying a neuromuscular response, potentially exposing the hamstring or the knee to injury.

Given the prevalence of hamstring and ACL injuries in football the aim of the present study was to determine the temporal pattern of eccentric hamstrings strength and dynamic stability post specific localised hamstrings fatigue. The hamstrings fatigue elicited in each player on the IKD was in line with the per cent decreases found in previous research of 20-30%, as a result of game specific fatigue protocols (Greig et al., 2008; Small et al., 2009). Eccentric strength will be quantified with measures of PkT, AvgPkT and °PkT at a variety of speeds, as this will replicate the demands on the muscle encountered in functional performance. BSS measures will be taken in two planes to indicate the dynamic stability of the player post fatigue. The temporal pattern in changes of these measures over a 72-hour period post fatigue may help to explain why the hamstring is experiencing deficits in eccentric strength as a result of fatigue, but also indicate if deficits are sustained what is their pattern of recovery. The significance of the 72hour temporal pattern will provide information to whether a player will be fully recovered in a fixture-congested period, as this is commonly the length of time between games. The

pattern of this recovery will potentially highlight where interventions could be implemented. It will also detail to medical staff, coaches and players their readiness for performance, potential need for adjustments to training protocols and also individualised programming.

## **4.2 Methodology:**

### ***4.2.1 Participants:***

Eighteen male professional football players completed the present study, with a mean age and standard deviation (SD) of  $21.5 \pm 3.09$  years, height  $181.98 \pm 5.43$  and body mass of  $77.7 \text{kg} \pm 5.06$ . All participants were screened to ensure suitability for the study in relation to inclusion/exclusion criteria (3.2.2) and provided written informed consent in accordance with the department and university ethical procedures as listed in the general methodology (3.2.1).

### ***4.2.2 Experimental Design:***

Before completion of the familiarisation and testing protocols, all players in the study were subjected to the appropriate anthropometric measures outlined in the general methodology (3.3). On completion of the relevant checks and consent being obtained players were then asked to complete a warm up on the cycle ergometer. The warm up for the localised fatigue protocol (3.3.3(a)) was completed on a cycle ergometer. Participants were asked to maintain a speed of 70-watts and completed at this moderate intensity for a period of ten minutes. Post completion of the warm up on the cycle ergometer participants were supervised through a series of dynamic stretches, which included the hamstrings, quadriceps, adductors, abductors and gastrocnemius. The stretches were completed for 12 repetitions within a 30 second period and this was consistent for all participants (Herda et al., 2008; Page., 2012). Static stretching was not considered as it has been shown to have a negative effect on dynamometer-measured strength (Herda et al., 2008; Siatras et al., 2008; Sekir et al., 2010; Page., 2012). Familiarisation trials were then completed for the localised fatigue protocol, IKD testing and BSS testing in line with experimental procedures listed in the general methodology, chapter 4 (3.3.1 and 3.3.2).

Post the familiarisation trials testing could proceed. Players were invited back to the laboratory 7 days' post familiarisation testing and completed measures on the IKD and BSS, the testing

protocols for each are detailed in the general methodology (3.3.1 and 3.3.2). Post obtaining baseline scores the players were then subjected to the localised fatigue protocol (3.3.3(a)). During completion of the fatigue protocol Borg's 6-20 point scale (1970) was used to record the participant's subjective rating of perceived exertion and was recorded at rest and post each set of 15 repetitions on the IKD. In addition to this heart rate (HR) was also recorded every 15 repetitions during each trial of each fatigue protocol using a HR monitor (Polar, Team system, Finland). Attendance time was noted for each player with regards baseline measures and the localised fatigue protocol and for the subsequent time points to monitor the temporal pattern post fatigue, they were asked to return at exactly the same time (Drust et al., 2005). To monitor the temporal pattern of recovery of the athlete IKD and BSS measurements were taken immediately post fatigue, 24 hours, 48 hours and 72 hours post fatigue, again all measurements were consistent with testing procedures detailed in the general methodology (3.3.1 and 3.3.2). The data analysis applied to the localised fatigue protocol was consistent with chapter 3.4 of the General Methodology.

#### ***4.2.3 Statistical Analysis:***

The  $PkT_{eccH}$ ,  $AvgPkT_{eccH}$  and  ${}^{\circ}PkT_{eccH}$  for all 3 testing speeds and dynamic stability outcome measures of OSI, A-P and M-L were determined at baseline, post localised fatigue and at consistent time points at 24, 48 and 72 hours. Tests for outliers, to identify if the data was normally distributed and sphericity, for equal variance in the data, were then completed, as detailed in chapter 3.5 of the general methodology. The data was then analysed using a one way repeated measures analysis of variance (ANOVA) for each output measure to establish whether there were significant differences between the base line values and the testing periods post fatigue, 24 hours, 48 hours and 72 hours post fatigue, determining if there was a significant main effect for recovery time. All statistical analysis was performed using PASW Statistics Editor 18.0 for windows (SPSS Inc, Chicago, USA) with an accepted significance level set at  $P \leq 0.05$  (3.5). Quadratic regression analysis was also completed as highlighted in the general methodology (3.5).

## 4.3 Results:

### 4.3.1 Eccentric Strength:

Below are the results displaying the effects of localised fatigue of the hamstring muscle group on player's (n = 20) dominant leg AvgPkJ<sub>eccH</sub>60°·s<sup>-1</sup>, AvgPkJ<sub>eccH</sub>150°·s<sup>-1</sup>, AvgPkJ<sub>eccH</sub>300°·s<sup>-1</sup> (figure 4.1(a)).

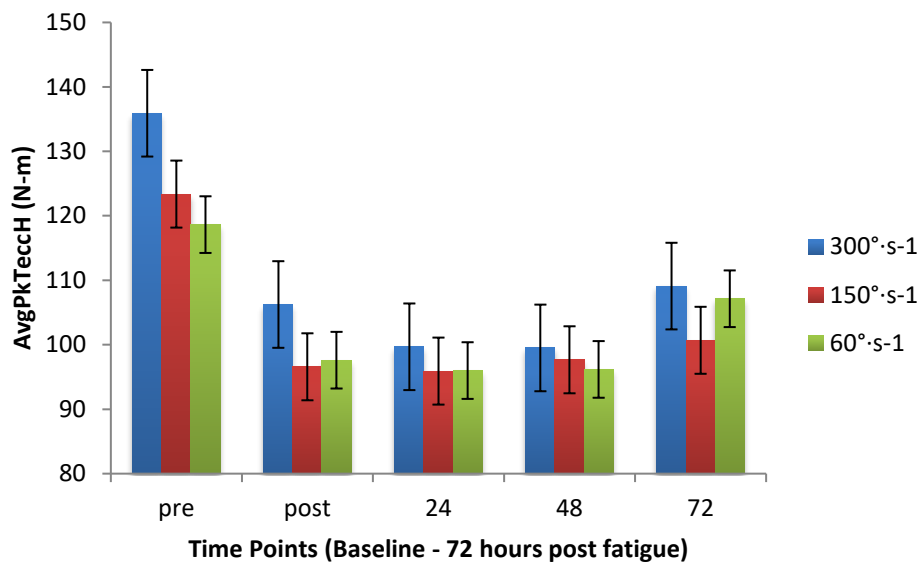


Figure 4.1(a): Temporal Pattern of Mean AvgPkJ<sub>eccH</sub> Values over a 72 hr Period Post Localised Hamstring Fatigue at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup> with Standard Error ( $\pm$  SE)

At the slowest test speed (60°·s<sup>-1</sup>) for AvgPkJ<sub>eccH</sub> analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except at 72 hr post, where no significant effect was found. Mean trends (baseline = 118.63 $\pm$ 23.8Nm and 72 hours post = 107.13 $\pm$ 20.3Nm) indicated that players AvgPkJ<sub>eccH</sub>60°·s<sup>-1</sup> had still not fully recovered post localised fatigue. Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of 150°·s<sup>-1</sup> with mean trend scores for baseline of 123.37 $\pm$ 20Nm and 72 hr post = 100.69 $\pm$ 21.3Nm. Thus, highlighting that players AvgPkJ<sub>eccH</sub>150°·s<sup>-1</sup> had not fully recovered. Similar results at the final fast testing speed of 300°·s<sup>-1</sup> also displayed significant differences ( $P \leq 0.05$ ) between all time periods when



compared to baseline. Again with mean trend scores indicating that players  $\text{AvgPkJ}_{\text{eccH}300^\circ\cdot\text{s}^{-1}}$  had not fully recovered at 72 hr (baseline =  $135.91 \pm 24.3\text{N}\cdot\text{m}$  and 72 hr =  $109.09 \pm 25.9\text{N}\cdot\text{m}$ ). On observation of the mean scores for all testing speeds  $60^\circ\cdot\text{s}^{-1}$ ,  $150^\circ\cdot\text{s}^{-1}$ ,  $300^\circ\cdot\text{s}^{-1}$  it can be seen that there is very little change in values when comparing time points post fatigue, 24 hr post fatigue and 48 hr post fatigue ( $\text{AvgPkJ}_{\text{eccH}60^\circ\cdot\text{s}^{-1}}$ : post fatigue =  $97.6 \pm 24.32\text{Nm}$ , 24 hr post fatigue =  $96 \pm 23.11\text{Nm}$  and 48 hr post fatigue =  $96.2 \pm 25.34\text{Nm}$ ,  $\text{AvgPkJ}_{\text{eccH}150^\circ\cdot\text{s}^{-1}}$ : post fatigue =  $96.58 \pm 17.84\text{Nm}$ , 24 hr post fatigue =  $95.91 \pm 19.06\text{Nm}$  and 48 hr post fatigue =  $97.66 \pm 23.49\text{Nm}$  and  $\text{AvgPkJ}_{\text{eccH}300^\circ\cdot\text{s}^{-1}}$ : post fatigue =  $106.24 \pm 24.32\text{Nm}$ , 24 hr post fatigue =  $99.68 \pm 23.11\text{Nm}$  and 48 hr post fatigue =  $99.50 \pm 25.34\text{Nm}$ ).

Displayed below is the quadratic regression analysis (Figure 4.1(b)) completed for  $\text{AvgPkJ}_{\text{eccH}}$  ( $n = 20$ ). The curves presented represent  $\text{AvgPkJ}_{\text{eccH}60^\circ\cdot\text{s}^{-1}}$ ,  $\text{AvgPkJ}_{\text{eccH}150^\circ\cdot\text{s}^{-1}}$ ,  $\text{AvgPkJ}_{\text{eccH}300^\circ\cdot\text{s}^{-1}}$ .

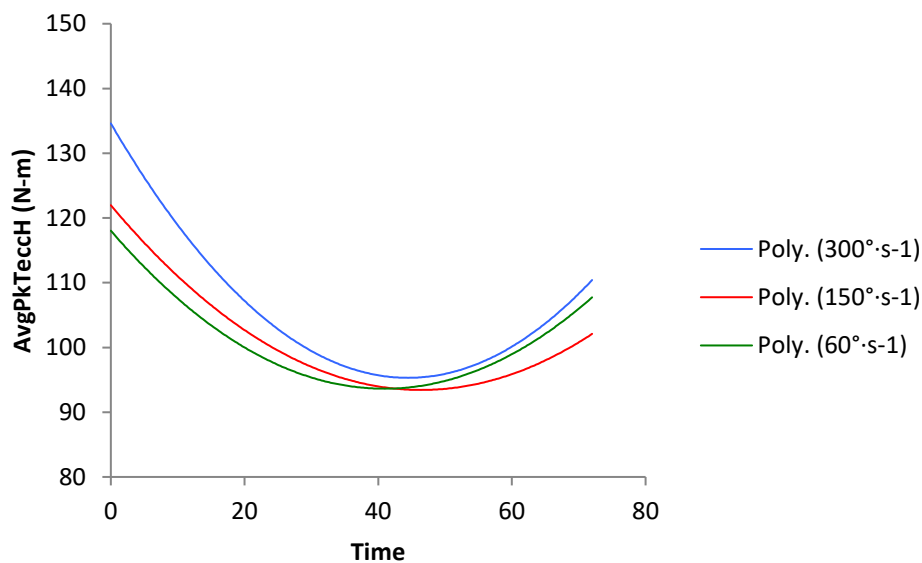


Figure 4.1(b): Quadratic Regression of  $\text{AvgPkJ}_{\text{eccH}}$  for Localised Hamstring Fatigue at Isokinetic Speeds of  $60^\circ\cdot\text{s}^{-1}$ ,  $150^\circ\cdot\text{s}^{-1}$  and  $300^\circ\cdot\text{s}^{-1}$

The quadratic regression indicates that the minima of the curve for  $\text{AvgPkJ}_{\text{eccH}}$  ranges between 38 and 41 hr for all testing speeds ( $300^\circ\cdot\text{s}^{-1} = 40.04\text{hrs}$ ,  $150^\circ\cdot\text{s}^{-1} = 38.35\text{hrs}$ ,  $60^\circ\cdot\text{s}^{-1} = 40.80\text{ hr}$ ) and continuation of the curve indicates that they would only return to baseline levels between 76 and 82 hr ( $300^\circ\cdot\text{s}^{-1} = 90.08\text{ hr}$ ,  $150^\circ\cdot\text{s}^{-1} = 76.71\text{hrs}$ ,  $60^\circ\cdot\text{s}^{-1} = 81.60\text{ hr}$ ). The quadratic

regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 4.1.

<b>Isokinetic Speed</b>	<b>Quadratic Regression Equation</b>	<b><math>r^2</math> Value</b>	<b>Minima in hr</b>	<b>Maxima in hr</b>
$300^\circ \cdot s^{-1}$	$y = 0.0199x^2 - 1.7678x + 134.6$	0.96	40.04	80.08
$150^\circ \cdot s^{-1}$	$y = 0.0132x^2 - 1.2288x + 121.97$	0.92	38.35	76.71
$60^\circ \cdot s^{-1}$	$y = 0.0146x^2 - 1.1932x + 118.03$	0.98	40.80	81.60

Table 4.1: Displaying the  $r^2$  values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves AvgPkJeccH at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$  and  $300^\circ \cdot s^{-1}$

It can be seen from the  $r^2$  values displayed in Table 4.1 that there is a strong correlation presented for all variables tested (AvgPkJeccH $60^\circ \cdot s^{-1}$ ,  $r^2 = 0.96$  AvgPkJeccH $150^\circ \cdot s^{-1}$ ,  $r^2 = 0.92$ , AvgPkJeccH $300^\circ \cdot s^{-1}$ ,  $r^2 = 0.98$ ). Thus, indicating that the minima and maxima hours presented in the predictive curve are strong.

Displayed below are the results displaying the effects of localised fatigue of the hamstring muscle group on player's (n = 20) dominant leg  $PkT_{eccH}60^{\circ}\cdot s^{-1}$ ,  $PkT_{eccH}150^{\circ}\cdot s^{-1}$ ,  $PkT_{eccH}300^{\circ}\cdot s^{-1}$  (figure 4.2(a)).

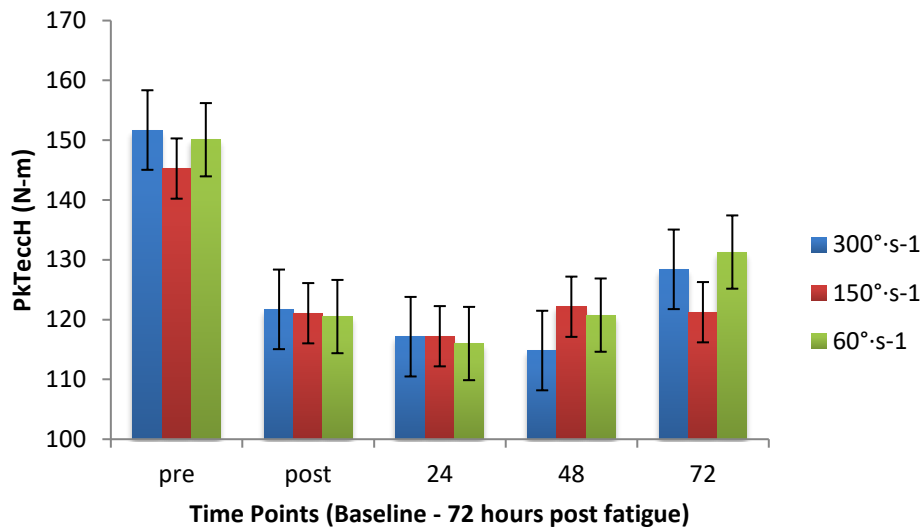


Figure 4.2(a): Temporal Pattern of Mean  $PkT_{eccH}$  Values over a 72 hr Period Post Localised Hamstring Fatigue at Isokinetic Speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$ ,  $300^{\circ}\cdot s^{-1}$  with Standard Error ( $\pm$  SE)

Results from the  $PkT_{eccH}$  measures highlighted that at the slow test speed of  $60^{\circ}\cdot s^{-1}$  analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except at 72 hr post, where no significant effect was found. Mean trends (baseline =  $150.08 \pm 32.68$  Nm and 72 hr post =  $131.29 \pm 28.01$  Nm) indicated that players  $PkT_{eccH}60^{\circ}\cdot s^{-1}$  had still not fully recovered post localised fatigue. Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of  $150^{\circ}\cdot s^{-1}$  with mean trend scores for baseline of  $145.25 \pm 22.17$  N·m and 72hr post =  $121.24 \pm 25.59$  N·m. Thus, highlighting that players  $PkT_{eccH}150^{\circ}\cdot s^{-1}$  had not fully recovered. Similar results at the final fast testing speed of  $300^{\circ}\cdot s^{-1}$  also displayed significant differences ( $P \leq 0.05$ ) between all time periods when compared to baseline. Again with mean trend scores indicating that players  $PkT_{eccH}300^{\circ}\cdot s^{-1}$  had not fully recovered at 72 hr (baseline =  $151.69 \pm 26.14$  Nm and 72 hr =  $128.41 \pm 25.68$  N·m). On observation of the mean scores for all testing speeds  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$  it can be seen that there is very little change in  $PkT_{eccH}$  values when comparing time points post fatigue, 24 hr post fatigue and 48 hr post fatigue ( $PkT_{eccH}60^{\circ}\cdot s^{-1}$ : post fatigue =  $120.51 \pm 23.08$  Nm, 24 hr post fatigue =  $115.99 \pm 25.74$  Nm and 48 hr post fatigue =

120.75±25.95Nm,  $PkT_{eccH}150^{\circ}\cdot s^{-1}$ : post fatigue = 121.07±23.03Nm, 24 hr post fatigue = 117.22±23.59Nm and 48 hr post fatigue = 122.15±26.23Nm and  $PkT_{eccH}300^{\circ}\cdot s^{-1}$ : post fatigue = 121.71±24.17Nm, 24 hr post fatigue = 117.14±23.52Nm and 48 hr post fatigue = 114.83±23.75Nm .

Displayed below is the quadratic regression analysis (Figure 4.2(b)) completed for  $PkT_{eccH}$  (n = 20). The curves presented represent  $PkT_{eccH}60^{\circ}\cdot s^{-1}$ ,  $PkT_{eccH}150^{\circ}\cdot s^{-1}$ ,  $PkT_{eccH}300^{\circ}\cdot s^{-1}$ .

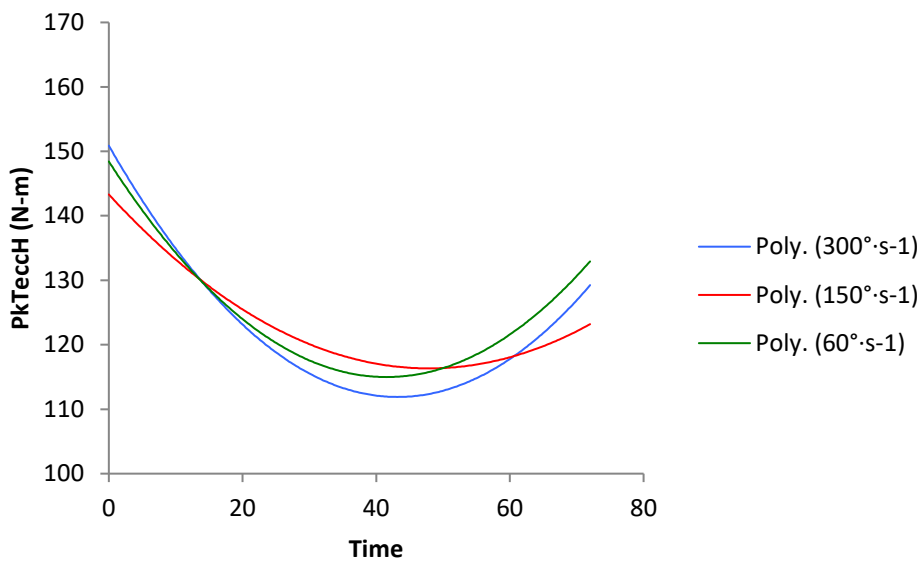


Figure 4.2(b): Quadratic Regression of  $PkT_{eccH}$  for Localised Hamstring Fatigue at Isokinetic Speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$

The quadratic regression indicates that  $PkT_{eccH}$  values between 35 and 41 hr ( $300^{\circ}\cdot s^{-1} = 41.01$  hr,  $150^{\circ}\cdot s^{-1} = 35.19$  hr,  $60^{\circ}\cdot s^{-1} = 38.35$  hr) and continuation of the curve indicates that they would only return to baseline levels between 70 and 82 hr ( $300^{\circ}\cdot s^{-1} = 82.03$ hrs,  $150^{\circ}\cdot s^{-1} = 70.38$  hr,  $60^{\circ}\cdot s^{-1} = 76.70$  hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 4.2.

Isokinetic Speed	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
300°·s <sup>-1</sup>	y = 0.0209x <sup>2</sup> - 1.8049x + 150.88	0.98	41.01	82.03
150°·s <sup>-1</sup>	y = 0.0118x <sup>2</sup> - 1.1271x + 143.31	0.84	35.19	70.38
60°·s <sup>-1</sup>	y = 0.0194x <sup>2</sup> - 1.6096x + 148.42	0.92	38.35	76.70

Table 4.2: Displaying the r<sup>2</sup> values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves for PkT<sub>eccH</sub> at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup>

It can be seen from the r<sup>2</sup> values displayed in table 4.2 that there is a strong correlation presented for variables tested (PkT<sub>eccH</sub>60°·s<sup>-1</sup>, r<sup>2</sup> = 0.92 and PkT<sub>eccH</sub>300°·s<sup>-1</sup>, r<sup>2</sup> = 0.98). A good correlation is displayed for PkT<sub>eccH</sub>150°·s<sup>-1</sup>, r<sup>2</sup> = 0.84. Thus, indicating that the minima and maxima hr presented in the predictive curve for PkT<sub>eccH</sub>60°·s<sup>-1</sup> and PkT<sub>eccH</sub>300°·s<sup>-1</sup> are strong. PkT<sub>eccH</sub>150°·s<sup>-1</sup> predictive curve also shows good predictive strength for the minima and maxima hours in the curve.

Displayed below are the results displaying the effects of localised fatigue of the hamstring muscle group on player's (n = 20) dominant leg  $^{\circ}\text{Pkt}_{\text{eccH}} 60^{\circ}\cdot\text{s}^{-1}$ ,  $^{\circ}\text{Pkt}_{\text{eccH}}150^{\circ}\cdot\text{s}^{-1}$ ,  $^{\circ}\text{Pkt}_{\text{eccH}}300^{\circ}\cdot\text{s}^{-1}$  (figure 4.3).

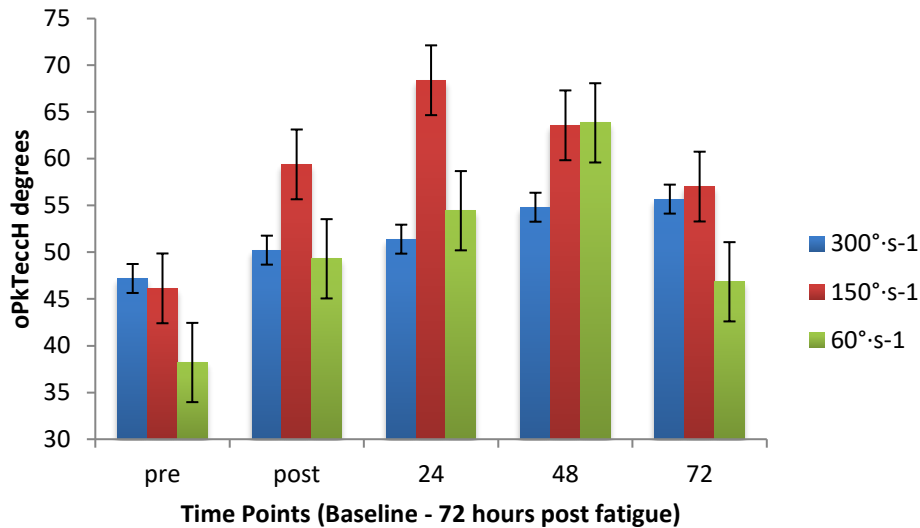


Figure 4.3: Temporal Pattern of Mean  $^{\circ}\text{Pkt}_{\text{eccH}}$  Values over a 72 hr Period Post Localised Hamstring Fatigue at Isokinetic Speeds of  $60^{\circ}\cdot\text{s}^{-1}$ ,  $150^{\circ}\cdot\text{s}^{-1}$ ,  $300^{\circ}\cdot\text{s}^{-1}$  with Standard Error ( $\pm$  SE)

Results from  $^{\circ}\text{Pkt}_{\text{eccH}}$  measures highlighted that at the slow test speed of  $60^{\circ}\cdot\text{s}^{-1}$  analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at time points 24 hr and 48 hr when compared to baseline, at all other time points no significant effect ( $P \geq 0.05$ ) was found. Significant differences ( $P \leq 0.05$ ) were found at time points 24 and 48 hr when compared against baseline at the testing speed of  $150^{\circ}\cdot\text{s}^{-1}$  with mean trend scores for baseline of  $46.14 \pm 17.48^{\circ}$ , 24 hr of  $68.40 \pm 18.70^{\circ}$  and 72 hr post =  $63.58 \pm 19.69^{\circ}$ . At the final fast testing speed of  $300^{\circ}\cdot\text{s}^{-1}$  no significant differences ( $P \geq 0.05$ ) between any of the time periods were found when compared to baseline or against each other. Polynomial regression analysis was not completed within  $^{\circ}\text{Pkt}_{\text{eccH}}$  due to the lack of significant effect fatigue had on angle.

### 4.3.2 Dynamic Stability:

Below are the results displaying the effects of localised fatigue of the hamstring muscle group on player's (n = 20) dominant leg OSI, A-P and M-L dynamic stability scores (figure 4.4(a)).

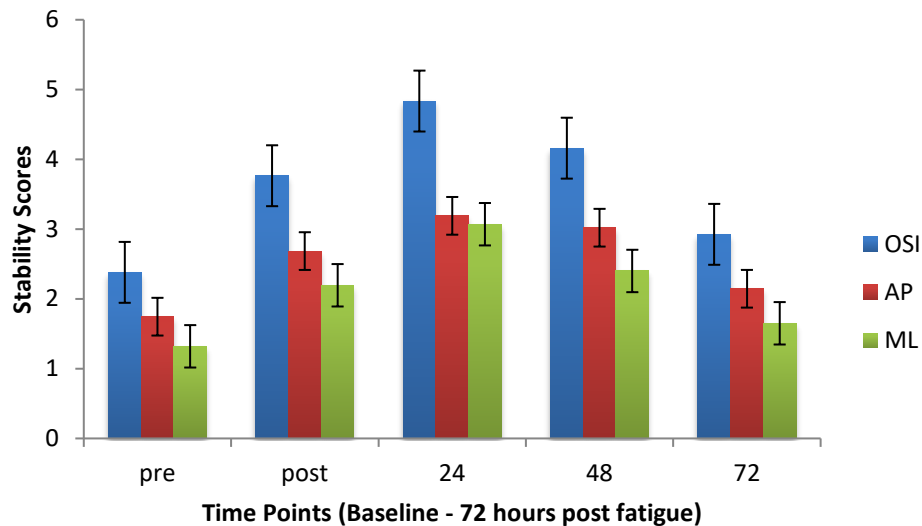


Figure 4.4(a): Temporal Pattern of Mean Dynamic Stability Values over a 72 hr Period Post Localised Hamstring Fatigue with Reference to OSI, A-P and M-L with Standard Error ( $\pm$  SE)

The OSI post an analysis of variance, indicated that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline. It was also identified that there were notable significant differences ( $P \leq 0.05$ ) within time points through the temporal pattern post fatigue, which were found between post fatigue and 24 hr post fatigue ( $\bullet 3.77 \pm 1.81$  and  $\bullet 4.84 \pm 2.31$ ), post fatigue and 72 hr post fatigue ( $\bullet 3.77 \pm 1.81$  and  $\bullet 2.93 \pm 1.20$ ), 24 hr post fatigue to 48 hr post fatigue ( $\bullet 4.84 \pm 2.31$  and  $\bullet 4.16 \pm 1.87$ ), 24 hr post fatigue to 72 hr post fatigue ( $\bullet 4.84 \pm 2.31$  and  $\bullet 2.93 \pm 1.20$ ) and 48 hr post fatigue to 72 hr post fatigue ( $\bullet 4.16 \pm 1.87$  and  $\bullet 2.93 \pm 1.20$ ). Analysis of variance for A-P presented significant findings ( $P \leq 0.05$ ) for all time periods when compared to baseline values. Significant differences ( $P \leq 0.05$ ) were also found for the time periods post fatigue to 72 hr post fatigue ( $\bullet 2.69 \pm 0.95$  and  $\bullet 2.15 \pm 0.87$ ), 24 hr post fatigue to 72 hr post fatigue ( $\bullet 3.19 \pm 1.26$  and  $\bullet 2.15 \pm 0.87$ ) and 48 hr post fatigue to 72 hr post fatigue ( $\bullet 3.02 \pm 1.29$  and  $\bullet 2.15 \pm 0.87$ ). Significant differences ( $P \leq 0.05$ ) were found at all-time points for M-L when compared to baseline, except for 72 hr where no significant difference was identified ( $P \geq 0.05$ ). Mean trends (baseline =  $\bullet 1.32 \pm 0.50$  and 72 hours post =  $\bullet 1.65 \pm 0.74$ ) indicated that players M-

L had still not fully recovered post localised fatigue. Results for M-L also showed that results displayed significant differences between the time points post fatigue to 24 hr post fatigue ( $\bullet 2.20 \pm 1.60$  and  $\bullet 3.07 \pm 2.10$ ) and post fatigue to 48 hr post fatigue ( $\bullet 2.20 \pm 1.60$  and  $\bullet 2.40 \pm 1.35$ ). On observation of the mean scores for OSI, A-P and M-L it can be seen that there is very little change in dynamic stability values when comparing time points 24 hr post fatigue and 48 hr post fatigue (OSI: 24 hr post fatigue =  $4.84 \pm 2.31$  and 48 hr post fatigue =  $4.16 \pm 1.87$ , A-P: 24 hr post fatigue =  $3.19 \pm 1.26$  and 48 hr post fatigue =  $3.02 \pm 1.29$  and M-L: 24 hr post fatigue =  $3.07 \pm 2.10$  and 48 hr post fatigue =  $2.40 \pm 1.35$ ).

Displayed below is the quadratic regression analysis (Figure 4.4(b)) completed for dynamic stability scores (n = 20). The curves presented represent OSI, A-P and M-L stability.

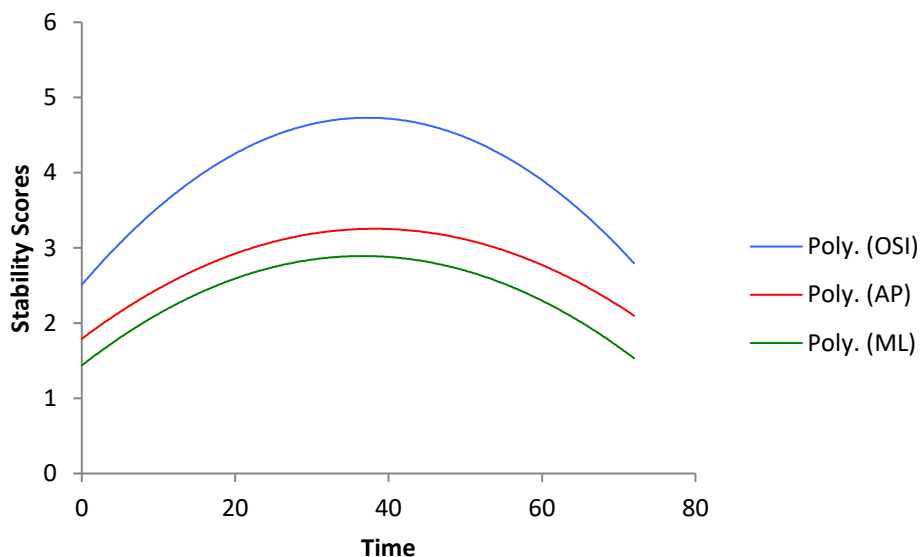


Figure 4.4(b): Quadratic Regression of Dynamic Stability Measures (OSI, A-P, M-L) for Localised Hamstring Fatigue at Isokinetic Speeds of  $60^{\circ} \cdot s^{-1}$ ,  $150^{\circ} \cdot s^{-1}$  and  $300^{\circ} \cdot s^{-1}$

The quadratic regression analysis and resultant predictive curve indicates that dynamic stability scores (OSI, A-P, M-L) minima between 35 and 42 hr (OSI = 38.03hrs, A-P = 40.47 hr, M-L = 35.47 hr) and continuation of the curve indicates that they would only return to baseline levels (maxima) between 70 and 81 hr (OSI = 76.05 hr, A-P = 80.94 hr, M-L = 70.94 hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 4.3.



Stability Plane	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
OSI	$y = -0.0016x^2 + 0.1193x + 2.5085$	0.91	38.03	76.05
A-P	$y = -0.001x^2 + 0.0768x + 1.7905$	0.97	40.47	80.94
M-L	$y = -0.0011x^2 + 0.0795x + 1.437$	0.85	35.47	70.94

Table 4.3: Displaying the r<sup>2</sup> values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves Dynamic Stability Scores of OSI, A-P and M-L

It can be seen from the r<sup>2</sup> values displayed in table 4.3 that there is a strong correlation presented for variables tested (OSI, r<sup>2</sup> = 0.91 and A-P, r<sup>2</sup> = 0.97). A good correlation is displayed for M-L, r<sup>2</sup> = 0.85. Thus, indicating that the minima and maxima hours presented in the predictive curve for OSI and A-P are strong. M-L stability predictive curve also shows good predictive strength for the minima and maxima hours in the curve.

• = where significant differences were found between mean scores.

#### **4.4 Discussion:**

The aim of the study was to investigate the temporal pattern of knee flexor eccentric strength at speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup>, 300°·s<sup>-1</sup> and dynamic stability (OSI, A-P and M-L) post localised hamstrings fatigue. Recent research in the area is limited thus making direct comparisons to previous findings difficult. The main focus of previous research has been orientated around soccer specific fatigue and the effect of this on these parameters throughout game play, but not sustained over a time period post event (Greig., 2008; Greig et al., 2009; Small et al., 2009).

The fatigue protocol utilised in this study was completed on the IKD in an open kinetic chain, through a linear plane. It is appreciated that the design of this fatigue protocol does not replicate the movement patterns experienced by players within game play. This said, consideration to previous research findings in to the effects of eccentric strength via soccer

specific fatigue protocols detail that reductions in eccentric strength from slow to fast isokinetic testing speeds ranged from 20 – 30% (Greig 2008; Greig et al., 2009; Small et al., 2009). These reductions provided the basis for the design of the localised fatigue protocol. The hamstrings were completely isolated and endured repetitive eccentric contractions until the strength of the hamstring elicited the same output, as it would post soccer specific fatigue. Completing the protocol on the IKD allowed conclusions to be drawn with regards the effect of this fatigue on the hamstring and ultimately its contribution to functional control and also dynamic stabilisation.

#### ***4.4.1 Eccentric Strength:***

Results displayed show that there were significant strength decreases at all testing speeds as a result of localised hamstrings fatigue, post localised protocol. These reductions in eccentric hamstrings strength were consistent with previous research on soccer specific fatigue protocols (Pincivero et al., 2000; Willems et al., 2002; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011). Although, these reductions were exhibited and reiterated findings in previous research it is appreciated this only explains the acute effects of fatigue and not the temporal pattern post and therefore no conclusions can be made with regards readiness for the next fixture in a congested period. In the present study mean results indicated that post fatigue, and when tracking the temporal pattern of recovery for a period of 72 hr, deficits were still exhibited within the measures of eccentric hamstring strength (measured at  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ , see figure 4.1(a) and 4.2(a)). Post analysis of variance between time points identified the decreases in  $AvgPkJ_{eccH}60^{\circ}\cdot s^{-1}$  and  $PkJ_{eccH}60^{\circ}\cdot s^{-1}$  were not significant ( $P\geq 0.05$ ) when compared to baseline. All other time periods when compared to baseline for  $AvgPkJ_{eccH}$  and  $PkJ_{eccH}$  at all speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$  were identified as having significant differences.

The mean scores for  $AvgPkJ_{eccH}$  and  $PkJ_{eccH}$  at all speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$  highlighted that there were very little differences between 24 hr and 48 hr post fatigue when compared against each other; with the differentiation of the quadratic regression curves for  $AvgPkJ_{eccH}$  and  $PkJ_{eccH}$  highlighting a minima between 35 and 42 hr. These findings emphasise that very little recovery was taking place within this 24 hr period post fatigue between measures at 24 hr and 48 hr post fatigue and thus emphasise the importance of what

players should be exposed to within this time frame. Any heavy load or high intense activity could potentially result in injury. Interestingly each of the testing conditions showed little recovery between 24 hr and 48 hr and players were found not to have fully recovered at 72 hr, potentially highlighting this as a key time period for any intervention to try to catalyse the recovery process in this window (Dupont et al., 2010; Bengtsson et al., 2014). It is also noted that the predictive curve of the quadratic regression analysis highlighted that it could take between 76 and 82 hr for the players to achieve baseline measures at the fast and mid testing speeds. Change in AvgPkt<sub>eccH</sub> can be attributed to time as the  $r^2$  values displayed are high, ranging from 0.92 – 0.98 across all isokinetic testing speeds. This indicates that there are little variance strength values exhibited across the temporal time pattern of testing. These findings were consistent with Pkt<sub>eccH</sub> at  $150^\circ \cdot s^{-1}$  and  $300^\circ \cdot s^{-1}$ , at  $60^\circ \cdot s^{-1}$  the  $r^2$  value displayed was slightly less ( $r^2 = 0.84$ ).

Findings also indicated that there were no significant changes in  $^\circ$ Pkt<sub>eccH</sub>. When analysing figure 6.3 it can be seen the angle slightly increases and peaks at 24 hr post fatigue and then gradually decreases back down to baseline level at 72 hr. This change in angle is interesting, and although not significant, still indicates that these increases in angle suggest that the muscle hits its peak torque at around mid-range and thus could potentially be weakening end of range where it would become more vulnerable to injury. This lengthened position of the hamstrings is closely associated with sustaining a muscle injury and the one most closely associated with the mechanism of injury (Orchard et al., 1997; Woods et al., 2004; Gabbe et al., 2006; Arnason et al., 2008; Engebretsen et al., 2010; Pizzari et al., 2010; Mackey et al., 2011; Opar et al., 2012; Mendiguchia et al., 2012; Serpell et al., 2012; Ropiak et al., 2012; Orchard et al., 2012; Ekstrand et al., 2016). Changes in  $^\circ$ Pkt<sub>eccH</sub> could indicate an increased risk of sustaining a hamstring injury (Small et al., 2009). Ideally, players would elicit their Pkt values at the end of range when performing an eccentric contraction. This is representative of the position the leg would be exposed to when decelerating through performance, a key aetiological contribution to injury. It is important to analyse the  $^\circ$ Pkt<sub>eccH</sub> in relation to AvgPkt<sub>eccH</sub> and Pkt<sub>eccH</sub> and the overall effect of fatigue on these variables. Results from the present study show us that although there are reductions in values of AvgPkt<sub>eccH</sub> and Pkt<sub>eccH</sub>, there are no significant changes in relation to  $^\circ$ Pkt<sub>eccH</sub>. Thus, indicating that where the player exhibits the most strength through range doesn't change, but it is the actual strength output that is affected.

#### ***4.4.2 Dynamic Stability:***

Similar findings were exhibited when analysing the results for dynamic stability measures. Mean scores indicate that post fatigue, and when tracking the temporal pattern of recovery for a period of 72 hr, deficits were still exhibited within the all measures of dynamic stability (OSI, A-P and M-L, see figure 4.4(a)). It was also noted that when analysing mean scores for dynamic stability there were very little differences between scores achieved by players with OSI and A-P, but the M-L scores displayed significantly better results. Mean scores also identified that for measures of M-L dynamic stability there is a considerable improvement in stability scores at 24 hr post fatigue and 48 hr post fatigue (24 hr post = 3.07 and 48 hr post = 2.40). The quadratic regression analysis also highlights these differences with M-L predicted to return to baseline levels at 71 hr (thus fully recovered within the 72 hr window) and A-P stability only predicted to return at 81 hr.

The justification for why M-L dynamic stability recovers while OSI and A-P function has not is unknown. Anatomical makeup of the joint and the constitution of mechanoreceptors within the joint may explain this. Zimny (1988) and Hogervorst et al., (1998) analysed the makeup of mechanoreceptors within the knee and particularly the ACL, with both papers indicating that there was a distinct scarcity of mechanoreceptors within the ACL. Debate continues through the research discussed within both papers whether this scarcity is significant within knee function. It is possible that the desensitisation of the intrafusal fibres within the muscle tissue (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015) has reduced the feedback provided from the muscle with regards dynamic stabilisation: thus, creating a reliance on the other receptors within the knee joint to provide feedback. The sheer density of receptors within the joint capsule, menisci, and other surrounding structures are creating a more efficient afferent signal, ultimately resulting in a better effected response to stabilise the knee through the M-L plane and the lack of receptors in the ACL has caused an electromechanical delay. Thus, exposing the ACL to greater loading due to delayed feedback.

Alternatively, decreased function of the intrafusal fibres within the muscle post fatigue (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015) can potentially expose the hamstrings or the supporting structures like the ACL to possible damage, due to its inability to create an efficient

enough response to muscle overstretch. In a position of knee extension and hip flexion decreased function of the muscle spindle and golgi tendon organ will result in an electromechanical delay (EMD) and the muscle then becomes exposed to overstretch resulting in a tear or damage to the tissue. When in a functional position of knee flexion decelerating in preparation to turn, where there is an excessive anterior force, the knee becomes reliant on the hamstring muscle group to create response to support the knee through these movement patterns. If there is a delay in this response, then the load will be exerted through the ACL and ultimately if this load is excessive a resultant injury will occur. Research has failed to identify which pathway is affected as a result of fatigue and only measures of the effected response to fatigue have been made (Lattinziio et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Riberio et al., 2010; Thomas et al., 2010; Gear., 2011; Gioftsidou et al., 2011; Changela et al., 2012). Both of the suggested explanations to why the results showed significant decreases in strength at all testing speeds and dynamic stability measures of A-P are plausible, based on the anatomical makeup of the knee and surrounding musculature accompanied with an appreciation of the physiological processes that occur when performing functional movement. It is important to note that although OSI represents a measure of dynamic stability this is a combination measure of the A-P and M-L planes. It is arguably more important to analyse which dynamic stability measures are deficient, as this will inform rehabilitation or preventative protocols, especially when associated with the mechanisms of injury.

#### ***4.4.3 Synopsis:***

The findings from this study, accompanied with the knowledge of basic functional anatomy, clearly indicate the hamstrings are a key stabilising muscle within the knee joint and localised fatigue has a detrimental effect on eccentric hamstring function. Clear relationships have been identified between reductions in hamstrings strength and dynamic stability. Evidence has clearly indicated that the pre cursors of injury and design of injury prevention programmes (Opar et al., 2012) are multi factorial with the majority of research highlighting that decreases in eccentric strength and neuromuscular functions are the main contributory factors (Mair et al., 1996; Koller et al., 2006; Sangnieer et al., 2007; Greig, 2008; Small et al., 2009; Delextrat, 2010; Torres et al., 2010). Results from the present study certainly support this notion. Epidemiological and aetiological research indicates that ACL injury in football is on the rise and that hamstring injuries have not decreased at all in the last decade (Askling et al., 2003; Agel et al., 2005; Arnason et al., 2008; Rahmana et al., 2009; Engebretson et al., 2010; Ekstrand

et al., 2011; Walden et al., 2011; Serpell et al., 2012; Ropiak et al., 2012; Serpell et al., 2012). The common mechanisms of injury for both of these injuries relate to linear motions either from a rapid acceleration/deceleration (Abebe et al., 2012; Opar et al., 2012; Ahmed et al., 2013) or an excessive anterior force through the knee joint (Alentorn-Geli et al., 2009; Walden et al., 2010). Consideration of the mechanism of injury in relation to the results of this study highlight potential mechanisms failing as a result of fatigue and making the hamstrings or the ACL more susceptible to injury.

Recent research in to ACL and hamstring injuries has identified the functional hamstrings to quadriceps ratio ( $H_{ecc}: Q_{conc}$ ) as a key contributory factor to sustaining injury (Wright et al., 2009; Delextrat et al., 2009). Fatigue has also been attributed to having a negative effect on  $H_{ecc}: Q_{conc}$  (Wright et al., 2009; Delextrat et al., 2009; Cohen et al., 2014). Conclusions drawn from these studies discuss the dominance of the quadriceps and attribute this to the changes in functional ratio and their findings are unclear as to whether it is the dominance of the quadriceps that results in reduced activation of the hamstrings or if it is failure of the hamstrings as a result of fatigue that causes the quadriceps to become more dominant. The significant findings from the present study highlight that this quadriceps dominance is more likely induced by the fatigue and decreased function of the hamstrings. Increased dominance of the quadriceps will result in a greater anterior force, which when performing functionally will place greater load through the ACL, thus increasing the chance of injury. Dependent on the functional movement performed the demand on the hamstrings will be increased. If the load is too great for the hamstrings and they cannot generate an equal or greater eccentric contraction to resist this load it increases the chance of the hamstring muscles sustaining damage due to overstretch.

The present study has analysed function of the hamstrings in relation to eccentric strength through 3 speeds and dynamic stability over a temporal period of 72 hr post localised fatigue. This localised fatigue was induced in an open kinetic chain position on the IKD. The advantages of this being that the IKD allowed the hamstring muscles to be solely isolated. However, open kinetic chain loading does not represent the demands placed on the lower limb through game play and it is noted that all of this loading was solely through a linear plane. Therefore, promoting the question were decreases in A-P stability associated with the type of exercise performed and if multi plane soccer specific fatigue was completed, would this result in decreases in M-L stability as well as A-P?

Further research investigating the temporal pattern of fatigue on hamstrings function in relation to dynamic stability and eccentric strength should be completed utilising a multi plane soccer specific fatigue protocol. Previous research has identified the effects of soccer specific fatigue on markers of eccentric strength via intermittent treadmill and multi plane soccer specific protocols (Greig 2008; Greig et al., 2009; Small et al., 2009). All of these studies were consistent in their findings and conclusions drawn with regard the deficits of eccentric strength post fatigue. However, none have analysed the temporal pattern over a 72 hr period or looked at the effects this loss in strength has on dynamic stability, nor have they utilised quadratic regression analysis to predict recovery time frames. Indications from this localised fatigue protocol indicate that functional strength and stability continues to reduce up to (42 hr) and doesn't fully recover until (82 hr). With the fastest speeds showing the longest periods of recovery, which is interesting as these high velocity movements are MOI's associated with hamstring and ACL injury. These findings have implications on the readiness of the athlete for competition in periods of fixture congestion, as reductions of hamstring strength to this degree could be an indicator why these injuries occur so frequently in football and ACL injuries are on the rise.

The localised fatigue protocol implemented in this study elicited the same fatigue deficits in the hamstring muscle group as found in the listed studies the load exerted was consistent and through range and did not represent loading experienced in game play. Utilisation of a multi plane soccer specific fatigue protocol must be given consideration in any further investigation, as it allows incorporation of backwards running, side stepping, turning and changes of direction that all load the hamstrings in different ways. This replication of the demands of game play with soccer specific movement patterns will subject the hamstrings to a variety of loading at different speeds, but findings from any further research would allow comparisons to be made to the present study.

#### **4.5 Conclusion:**

Eccentric hamstrings peak torque, average peak torque and dynamic stability measures of OSI, A-P and M-L were observed to deteriorate post localised hamstrings fatigue and remained low for a period of 72 hr post fatigue. The only exceptions to this were at 72 hr no effect was found for M-L and slow eccentric hamstrings peak torque and average peak torque measures. There was also no effect identified for angle of peak torque measures post fatigue of throughout the

temporal measures up to 72 hr post fatigue. The significance of these findings highlight that the athlete could be more susceptible to injury within and potentially beyond the 72 hr period, where they may be expected to train or play again post fatigue. It also highlights that the proprioceptive response is depleted for up to a 72 hr period for movement through an A-P plane, thus highlighting the potential to expose the ACL to more stress. This indicates that the measures of eccentric strength and A-P dynamic stability are useful markers to be utilised as predictors of injury, but also that there is a need to develop hamstrings strength endurance to increase stability of the knee through performance and also make them resistant to muscular strain. The use of predictive curves to indicate minima and maxima curves through this period of recovery, indicate a players readiness for the next game in periods of fixture congestion or alternatively can inform training planning. Potentially, making them a key monitoring tool to help reduce the occurrence of hamstring and ACL injury in modern day football.



## **Chapter 5: The Temporal Pattern of Recovery in Eccentric Hamstrings Strength and Dynamic Stability Post-Soccer Specific Fatigue**

### **5.1 Introduction:**

Epidemiological and aetiological data from the past decade clearly indicates that non-contact musculoskeletal injuries, such as hamstring and ACL injuries more frequently occur within game when players are fatigued (Bjordal et al., 1997; Woods et al., 2004; Fauno et al., 2006; Arnason et al., 2008; Engebretsen et al., 2010; Ekstrand et al., 2011; Serpell et al., 2012).

Basic functional anatomy highlights the link between the two injuries and possible implications a reduction in hamstrings function can have on the knee. The hamstrings are made up of three muscles the biceps femoris, semitendinosus and semimembranosus with each muscle having a vital role within functional control during performance. Like hamstring injuries, the most common MOI (Abebe et al., 2012; Opar et al., 2012; Ahmed et al., 2013) of injury for an ACL is a deceleration or a deceleration combined with a change of direction. Additional MOI associated with the ACL are landing in full extension or pivoting in full extension while the foot is planted (McNair et al., 1990; Noyes et al., 1990), with research indicating 70% - 84% of ACL injuries are sustained via non-contact mechanisms (Feagin et al., 1985; Boden et al., 2000; Fauno et al., 2006). Throughout all of these movement patterns a failure or decrease of hamstrings strength or a reduction in dynamic stability would expose the ACL to an increased load due to over dominance of the quadriceps or a lack of control from the hamstring through particular movement patterns creating excessive anterior loading through the knee (Alentorn-Geli et al., 2009; Walden et al., 2010). When this occurs and the knee falls in to 20° - 30° of flexion it is considered to be the most compromising movement pattern for the ACL, singular rotational movements do not stress the ACL. The functional role of the hamstrings is to resist these movement patterns.

Through game play there is a reduction of eccentric hamstrings strength (Koller et al., 2006; Arnason et al., 2008; Greig et al., 2008; Greig et al., 2009; Small et al., 2009; Opar et al., 2012). Potential effects of this reduction in strength are reduced contribution of the hamstrings to knee stability, but also this decrease makes the muscle less resistant to the loads that it will experience during game play, ultimately exposing it and increasing the chance of muscle injury. Hence the hamstrings and hamstrings strength play a key and pivotal role during functional

play. Greig et al., (2008) identified the temporal pattern of eccentric hamstrings strength during a treadmill protocol, which replicated the demands of game play. The findings of their research identified a reduction in eccentric hamstrings strength at the end of each half and notably post 90 minutes a reduction of 20 – 30% in peak torque values when measured on the IKD at speeds of  $180^{\circ} \text{ s}^{-1}$ ,  $300^{\circ} \text{ s}^{-1}$ . Deficits for  $60^{\circ} \text{ s}^{-1}$  were also identified, however these were not as great. Further research completed by Small et al., (2009) furthered this research by utilising a free running game specific protocol that replicated the demands of soccer. They justified this by theorising that treadmill running did not include any cutting movements, which are often experienced in game play. Findings indicate similar fatigue effects on strength through the 90 minutes to the treadmill protocols. Both pieces of research are clear indicators that the fatigue effects induced by game play create significant deficits on players functional hamstring strength and these deficits may also be associated with a decreased dynamic stabilisation of the knee, which has also been highlighted in current literature (Riberio et al., 2008; Riberio et al., 2010; Gear 2011; Changela et al., 2012). This therefore could increase a player's chance of sustaining a hamstring or ACL injury. Due to the increasing demands of the game on players and the frequency of fixture congestion throughout the season, where players would be expected to play 2 games within a 72-hour period, it is important to determine the temporal pattern through an extended period post fatigue.

In order to inform periodised training, recovery strategies or intervention strategies it is essential that an understanding be developed of the temporal pattern of the hamstrings post soccer specific fatigue. The justification of isolating and looking at the hamstrings comes as a result of the essential role they play as a stabilising muscle within functional movement (Yeow et al., 2013) and that the quadriceps have been shown to have an increased resistance to fatigue (Sangnier et al., 2007). It is clear that fatigue causes a reduction in hamstrings strength (Mair et al., 1996; Small et al., 2008; Greig, 2008; Small et al., 2009; Delextrat, 2010; Opar et al., 2012) and this reduction in strength results in a dominance of the quadriceps, within running function (Sangnier et al., 2007). This dominance then creates a larger anterior shearing force, which has been strongly associated with ACL injury (Yu et al., 2007). The reduction in hamstrings strength leaves the muscle vulnerable to injury (Askling et al., 2003; Arnason et al., 2008; Engbretsen et al., 2010; Ekstrand et al., 2011; Mackey et al., 2011; Petersen et al., 2011). When the hamstring muscle is stressed and exposed to increased loads when functionally performing the neuromuscular response will remain, which is to request the hamstrings to dynamically stabilise the knee. If this load becomes too great this will result in a hamstring

injury or if the muscle just fails to stabilise it could result in excess stress to the ACL, leaving it vulnerable to rupture.

Given the current evidence in relation to the importance of hamstrings strength to decreasing the risk of injury, the aim of the present study was to determine the temporal pattern of eccentric hamstrings strength and dynamic stability post the SAFT<sup>90</sup> free running soccer fatigue protocol. Due to the current demands of the modern game it seems logical to identify the effects a 90 minute fatigue protocol has on eccentric hamstrings strength and dynamic stability and track this over a 72 hr period. This would educate players, coaches and medical staff on how to periodise their training, but also highlight where potential interventions or recovery strategies could be employed to accelerate this recovery. The protocol utilised will be the SAFT<sup>90</sup> as previously utilised in research by (Small et al., 2009). This protocol has been specifically designed to replicate the demands of Championship level football and has been shown to elicit similar deficits to hamstrings strength as other soccer specific fatigue protocols completed on treadmills (Greig et al., 2008; Greig et al., 2009). Differences between the two protocols are within the movement patterns performed. In the SAFT<sup>90</sup> a range of movement patterns are completed, such as forwards/backwards running, turning, medial-lateral movements and sidestepping; all actions that are performed by players during game play that cannot be replicated on a treadmill.

Eccentric strength was quantified with measures of PkT, AvgPkT and °PkT at a variety of speeds, as this replicates the demands on the muscle encountered in functional performance. In contrast BSS measures were taken through two planes to indicate the dynamic stability of the player post fatigue. The temporal pattern in changes of these measures over a 72 hr period post fatigue will identify how hamstrings function changes through a 90 min fatigue protocol, but also if these changes are linked directly to a reduction in dynamic stability. By tracking the measures for 72 hr it will also allow suggestions to be made for the best time to implement interventions and also direct medical staff as to whether the player is recovered and ready to compete in a fixture congested period.

## **5.2 Methodology:**

### **5.2.1 *Participants:***

Eighteen male professional soccer players completed the present study, with a mean age and SD of  $22.94 \pm 4.57$  years, height  $185.38 \pm 4.22$  and body mass of  $75.91 \text{kg} \pm 6.38$ . All participants were screened to ensure suitability for the study in relation to inclusion/exclusion criteria (3.2.2) and provided written informed consent in accordance with the department and university ethical procedures as listed in the general methodology (3.2.1).

### **5.2.2 *Experimental Design:***

Before completion of the familiarisation and testing protocols, all players in the study were subjected to the appropriate anthropometric measures outlined in the general methodology (3.3). On completion of the relevant checks and consent being obtained players were then asked to complete a warm up, which consisted of 10 min of the SAFT<sup>90</sup> protocol (3.3.3(b)). Post completion of the warm up participants were supervised through a series of dynamic stretches, which included the hamstrings, quadriceps, hip adductors and abductors and gastrocnemius. The stretches were completed for 12 repetitions within a 30 second period and this was consistent for all participants (Herda et al., 2008; Page, 2012). Static stretching was not considered as it has been shown to have a negative effect on dynamometer-measured strength (Herda et al., 2008; Siatras et al., 2008; Sekir et al., 2010; Page, 2012). This was carried out before completion of any familiarisation or testing protocols. Familiarisation trials were then completed for the soccer specific fatigue protocol, IKD testing and BSS testing (3.3.3(b), 3.3.1 and 3.3.2).

Post the familiarisation trials testing could proceed. Players were invited back to the laboratory 7 days' post familiarisation testing and completed measures on the IKD and BSS, the testing protocols for each are detailed in the general methodology (3.3.1 and 3.3.2). Post obtaining baseline scores the players were then subjected to the SAFT<sup>90</sup> soccer specific fatigue protocol (3.3.3(b)). During completion of the fatigue protocol Borg's 6-20 point scale (1970) was used to record the participant's subjective rating of perceived exertion and was recorded at rest and post each 15 min period of the SAFT<sup>90</sup>. In addition to this heart rate (HR) was also recorded every 15 repetitions during each trial of each fatigue protocol using a HR monitor (Polar, Team

system, Finland). Attendance time was noted for each player with regards baseline measures and the SAFT<sup>90</sup> protocol and for the subsequent time points to monitor the temporal pattern post fatigue, they were asked to return at exactly the same time (Drust et al., 2005). To monitor the temporal pattern of recovery of the athlete IKD and BSS measurements were taken immediately post fatigue, 24 hr, 48 hr and 72 hr post fatigue, again all measurements were consistent with testing procedures detailed in the general methodology (3.3.1 and 3.3.2). The data analysis applied to the soccer specific fatigue protocol was consistent with chapter 3.4 of the General Methodology.

### ***5.2.3 Statistical Analysis:***

The  $PkT_{eccH}$ ,  $AvgPkT_{eccH}$  and  ${}^{\circ}PkT_{eccH}$  for all 3 testing speeds and dynamic stability outcome measures of OSI, A-P and M-L were determined at baseline, post localised fatigue and at consistent time points at 24, 48 and 72 hours. Tests for outliers, to identify if the data was normally distributed and sphericity, for equal variance in the data, were then completed, as detailed in chapter 3.5 of the general methodology. The data was then analysed using a one way repeated measures analysis of variance (ANOVA) for each output measure to establish whether there were significant differences between the base line values and the testing periods post fatigue, 24 hours, 48 hours and 72 hours post fatigue, determining if there was a significant main effect for recovery time. All statistical analysis was performed using PASW Statistics Editor 18.0 for windows (SPSS Inc, Chicago, USA) with an accepted significance level set at  $P \leq 0.05$  (3.5). Quadratic regression analysis was completed as described in the general methodology (3.5).

### 5.3 Results:

#### 5.3.1 Eccentric Strength:

Below are the results displaying the effects of soccer specific fatigue on the hamstring muscle group of player's (n = 18) dominant leg AvgPkJ<sub>T<sub>e</sub>cch</sub>60°·s<sup>-1</sup>, AvgPkJ<sub>T<sub>e</sub>cch</sub>150°·s<sup>-1</sup>, AvgPkJ<sub>T<sub>e</sub>cch</sub>300°·s<sup>-1</sup> (figure 5.1(a)).

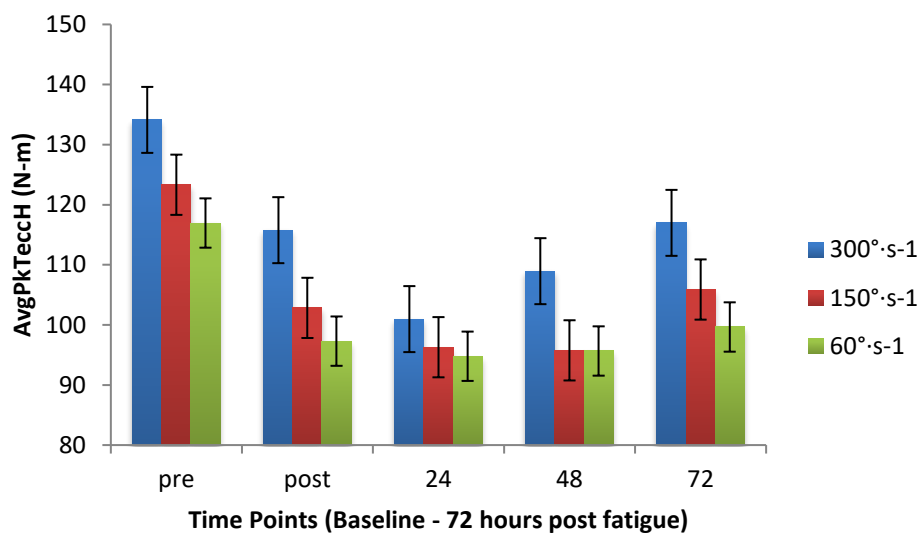


Figure 5.1(a): Temporal Pattern of Mean AvgPkJ<sub>T<sub>e</sub>cch</sub> Values over a 72 hr Period Post Soccer Specific (SAFT<sup>90</sup>) Fatigue at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup>, 300°·s<sup>-1</sup> with Standard Error ( $\pm$  SE)

At the slowest test speed (60°·s<sup>-1</sup>) for AvgPkJ<sub>T<sub>e</sub>cch</sub> analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline. Mean trends (baseline = 116.95 $\pm$ 28.45N·m, post fatigue = 97.30 $\pm$ 17.54N·m, 24 hr post = 94.78 $\pm$ 12.65N·m, 48hr post = 95.66 $\pm$ 17.53N·m and 72 hr post = 99.65 $\pm$ 16.69N·m) highlight that players AvgPkJ<sub>T<sub>e</sub>cch</sub>60°·s<sup>-1</sup> had not fully recovered post soccer specific fatigue when comparing all time points to baseline. Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of 150°·s<sup>-1</sup> with mean trend scores for baseline = 123.32 $\pm$ 25.04N·m, post fatigue = 102.83 $\pm$ 25.46N·m, 24 hr post = 96.29 $\pm$ 20.95N·m, 48 hr post = 95.76 $\pm$ 21.55N·m and 72 hr post = 105.89 $\pm$ 21.77N·m. Thus, highlighting that players AvgPkJ<sub>T<sub>e</sub>cch</sub>150°·s<sup>-1</sup> had not fully recovered. Similar results at the final fast testing speed of

$300^{\circ}\cdot s^{-1}$  also displayed significant differences ( $P \leq 0.05$ ) between all time periods when compared to baseline. Again with mean trend scores indicating that players  $AvgPkJ_{eccH}300^{\circ}\cdot s^{-1}$  had not fully recovered at 72 hr (baseline =  $134.11 \pm 34.65 N\cdot m$ , post fatigue =  $115.76 \pm 33.50 N\cdot m$ , 24 hr post =  $100.97 \pm 27.00 N\cdot m$ , 48 hr post =  $108.94 \pm 31.04 N\cdot m$  and 72 hr post =  $116.98 \pm 29.04 N\cdot m$ ). On observation of the mean scores for all testing speeds  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$ ,  $300^{\circ}\cdot s^{-1}$  it can be seen that there is very little change in  $AvgPkJ_{eccH}$  values when comparing time points 24 hr post fatigue and 48 hr post fatigue ( $AvgPkJ_{eccH}60^{\circ}\cdot s^{-1}$ : 24 hr post fatigue =  $94.78 \pm 12.65 Nm$  and 48 hr post fatigue =  $95.66 \pm 17.53 Nm$ ,  $AvgPkJ_{eccH}150^{\circ}\cdot s^{-1}$ : 24 hours post fatigue =  $96.29 \pm 20.95 Nm$  and 48 hr post fatigue =  $95.76 \pm 21.55 Nm$  and  $PkJ_{eccH}300^{\circ}\cdot s^{-1}$ : 24 hr post fatigue =  $100.97 \pm 27.00 Nm$  and 48 hr post fatigue =  $108.94 \pm 31.04 Nm$ ).

Displayed below is the quadratic regression analysis (Figure 5.1(b)) completed for  $AvgPkJ_{eccH}$  ( $n = 18$ ). The curves presented represent  $AvgPkJ_{eccH}60^{\circ}\cdot s^{-1}$ ,  $AvgPkJ_{eccH}150^{\circ}\cdot s^{-1}$ ,  $AvgPkJ_{eccH}300^{\circ}\cdot s^{-1}$ .

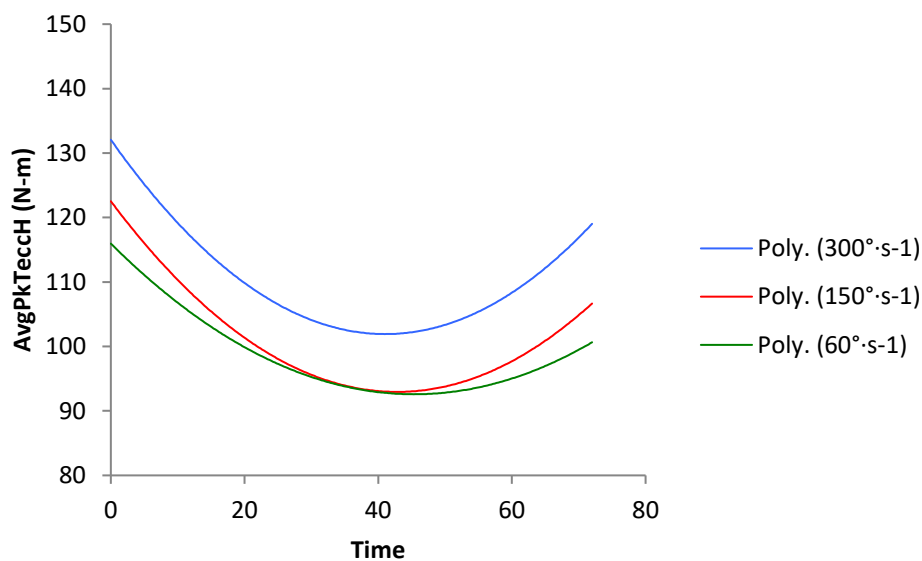


Figure 5.1(b): Quadratic Regression of  $AvgPkJ_{eccH}$  Post Soccer Specific (SAFT<sup>90</sup>) Fatigue at Isokinetic Speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$

The quadratic regression indicates that  $AvgPkJ_{eccH}$  values between 35 and 41 hr ( $300^{\circ}\cdot s^{-1} = 35.84$  hr,  $150^{\circ}\cdot s^{-1} = 40.61$  hr,  $60^{\circ}\cdot s^{-1} = 39.09$  hr) and continuation of the curve indicates that they would only return to baseline levels between 72 and 82 hr ( $300^{\circ}\cdot s^{-1} = 71.67$  hr,  $150^{\circ}\cdot s^{-1} =$

81.23 hr,  $60^\circ \cdot s^{-1} = 78.18$  hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 5.1.

<b>Isokinetic Speed</b>	<b>Quadratic Regression Equation</b>	<b><math>r^2</math> Value</b>	<b>Minima in hr</b>	<b>Maxima in hr</b>
$300^\circ \cdot s^{-1}$	$y = 0.0179x^2 - 1.468x + 132.06$	0.86	35.84	71.67
$150^\circ \cdot s^{-1}$	$y = 0.0161x^2 - 1.3812x + 122.53$	0.97	40.61	81.23
$60^\circ \cdot s^{-1}$	$y = 0.0114x^2 - 1.0302x + 115.95$	0.94	39.09	78.18

Table 5.1: Displaying the  $r^2$  values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves AvgPkT<sub>eccH</sub> at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$  and  $300^\circ \cdot s^{-1}$

It can be seen from the  $r^2$  values displayed in table 5.1 that there is a strong correlation presented for all variables tested (AvgPkT<sub>eccH</sub> $60^\circ \cdot s^{-1}$ ,  $r^2 = 0.86$  AvgPkT<sub>eccH</sub> $150^\circ \cdot s^{-1}$ ,  $r^2 = 0.97$ , AvgPkT<sub>eccH</sub> $300^\circ \cdot s^{-1}$ ,  $r^2 = 0.94$ ). Thus, indicating that the minima and maxima hours presented in the predictive curve are strong.



Displayed below are the results displaying the effects of soccer specific fatigue on the hamstring muscle group of player's (n = 18) dominant leg  $PkT_{eccH60^{\circ}\cdot s^{-1}}$ ,  $PkT_{eccH150^{\circ}\cdot s^{-1}}$ ,  $PkT_{eccH300^{\circ}\cdot s^{-1}}$  (figure 5.2(a)).

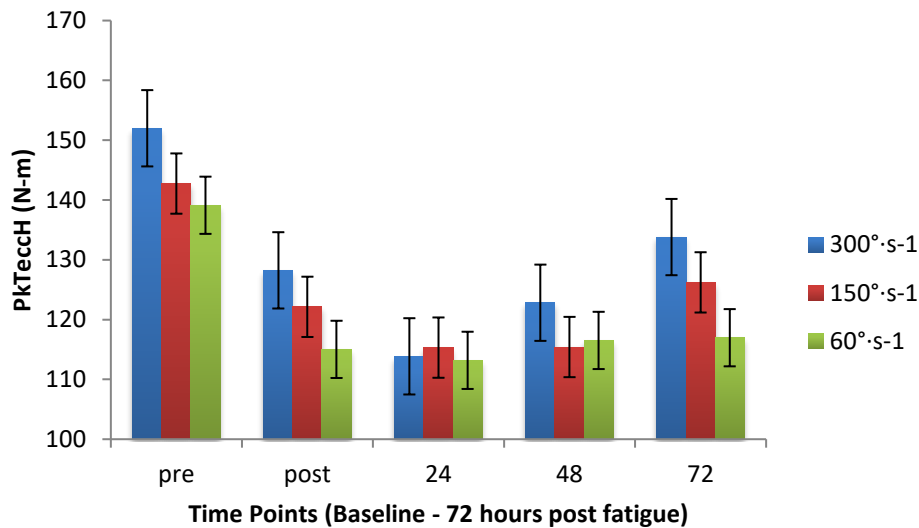


Figure 5.2(a): Temporal Pattern of Mean  $PkT_{eccH}$  Values over a 72 hr Period Post Soccer Specific (SAFT<sup>90</sup>) Fatigue at Isokinetic Speeds of  $60^{\circ}/s^{-1}$ ,  $150^{\circ}/s^{-1}$  and  $300^{\circ}/s^{-1}$  with Standard Error ( $\pm$  SE).

Results from  $PkT_{eccH}$  measures highlighted that at the slow test speed of  $60^{\circ}\cdot s^{-1}$  analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline. Mean trends (baseline =  $139.11 \pm 33.97 N\cdot m$ , post fatigue =  $115.02 \pm 19.89 N\cdot m$ , 24 hr post =  $113.19 \pm 22.30 N\cdot m$ , 48 hr post =  $116.52 \pm 25.21 N\cdot m$  and 72 hr post =  $116.97 \pm 21.59 N\cdot m$ ) highlight that player's  $PkT_{eccH60^{\circ}\cdot s^{-1}}$  had not fully recovered post soccer specific fatigue at any time point when compared to baseline. Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of  $150^{\circ}\cdot s^{-1}$  with mean trend scores for baseline =  $142.74 \pm 29.92 N\cdot m$ , post fatigue =  $122.13 \pm 26.36 N\cdot m$ , 24 hr post =  $115.32 \pm 17.14 N\cdot m$ , 48 hr post =  $115.42 \pm 22.34 N\cdot m$  and 72 hr post =  $126.22 \pm 22.07 N\cdot m$ . Thus, highlighting that players  $PkT_{eccH150^{\circ}\cdot s^{-1}}$  had not fully recovered. Similar results at the final fast testing speed of  $300^{\circ}\cdot s^{-1}$  also displayed significant differences ( $P \leq 0.05$ ) between all time periods when compared to baseline. Again with mean trend scores indicating that players  $PkT_{eccH300^{\circ}\cdot s^{-1}}$  had not fully recovered at 72 hr (baseline =  $151.99 \pm 34.82 N\cdot m$ , post fatigue =  $128.24 \pm 32.64 N\cdot m$ , 24 hr post =  $113.86 \pm 24.66 N\cdot m$ , 48 hr

post =  $122.82 \pm 29.92 \text{ N}\cdot\text{m}$  and 72 hr post =  $133.80 \pm 31.84 \text{ N}\cdot\text{m}$ ). On observation of the mean scores for all testing speeds  $60^\circ\cdot\text{s}^{-1}$ ,  $150^\circ\cdot\text{s}^{-1}$  and  $300^\circ\cdot\text{s}^{-1}$  it can be seen that there is very little change in  $\text{PkT}_{\text{eccH}}$  values when comparing time points 24 hr post fatigue and 48 hr post fatigue ( $\text{PkT}_{\text{eccH}60^\circ\cdot\text{s}^{-1}}$ : 24 hr post fatigue =  $113.19 \pm 22.30 \text{ Nm}$  and 48 hr post fatigue =  $116.52 \pm 25.21 \text{ Nm}$ ,  $\text{PkT}_{\text{eccH}150^\circ\cdot\text{s}^{-1}}$ : 24 hr post fatigue =  $115.32 \pm 17.14 \text{ Nm}$  and 48 hr post fatigue =  $115.42 \pm 22.34 \text{ Nm}$  and  $\text{PkT}_{\text{eccH}300^\circ\cdot\text{s}^{-1}}$ : 24 hr post fatigue =  $113.86 \pm 24.66 \text{ Nm}$  and 48 hr post fatigue =  $122.82 \pm 29.92 \text{ Nm}$  .

Displayed below is the quadratic regression analysis (Figure 5.2(b)) completed for  $\text{PkT}_{\text{eccH}}$  (n = 18). The curves presented represent  $\text{PkT}_{\text{eccH}60^\circ\cdot\text{s}^{-1}}$ ,  $\text{PkT}_{\text{eccH}150^\circ\cdot\text{s}^{-1}}$ ,  $\text{PkT}_{\text{eccH}300^\circ\cdot\text{s}^{-1}}$ .

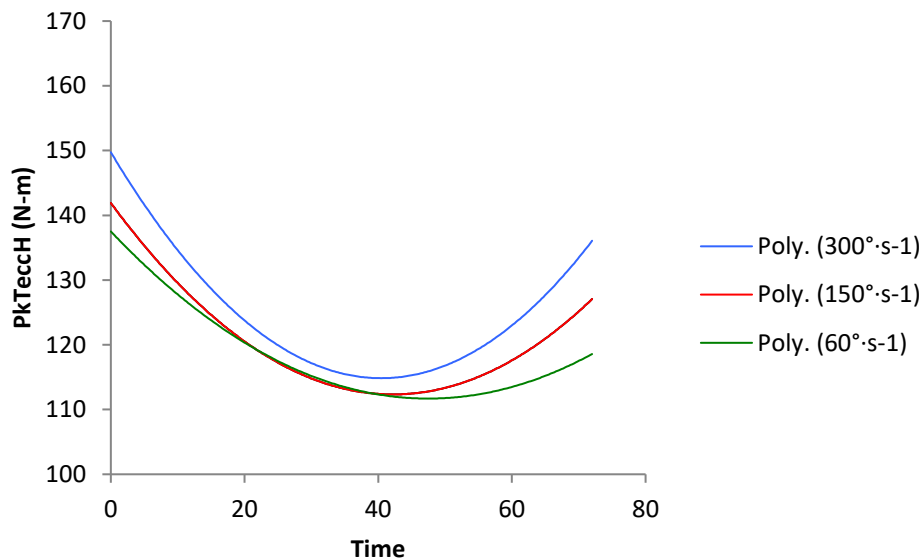


Figure 5.2(b): Quadratic Regression of  $\text{PkT}_{\text{eccH}}$  Post Soccer Specific (SAFT90) Fatigue at Isokinetic Speeds of  $60^\circ\cdot\text{s}^{-1}$ ,  $150^\circ\cdot\text{s}^{-1}$  and  $300^\circ\cdot\text{s}^{-1}$

The quadratic regression indicates that  $\text{PkT}_{\text{eccH}}$  values between 36 and 41 hr ( $300^\circ\cdot\text{s}^{-1} = 36.43$  hr,  $150^\circ\cdot\text{s}^{-1} = 40.49$  hr,  $60^\circ\cdot\text{s}^{-1} = 36.60$  hr) and continuation of the curve indicates that they would only return to baseline levels between 76 and 82 hr ( $300^\circ\cdot\text{s}^{-1} = 72.87$  hr,  $150^\circ\cdot\text{s}^{-1} = 80.98$  hr,  $60^\circ\cdot\text{s}^{-1} = 73.21$  hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 5.2.

Isokinetic Speed	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
300°·s <sup>-1</sup>	y = 0.0213x <sup>2</sup> - 1.725x + 149.74	0.87	36.43	72.87
150°·s <sup>-1</sup>	y = 0.0166x <sup>2</sup> - 1.4009x + 141.9	0.97	40.49	80.98
60°·s <sup>-1</sup>	y = 0.0114x <sup>2</sup> - 1.0873x + 137.51	0.88	36.60	73.21

Table 5.2: Displaying the r<sup>2</sup> values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves PkTeccH at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup>

It can be seen from the r<sup>2</sup> values displayed in table 5.2 that there is a strong correlation presented for variables tested (PkT<sub>eccH</sub>150°·s<sup>-1</sup>, r<sup>2</sup> = 0.97). A good correlation is displayed for PkT<sub>eccH</sub>60°·s<sup>-1</sup>, r<sup>2</sup> = 0.88 and PkT<sub>eccH</sub>300°·s<sup>-1</sup>, r<sup>2</sup> = 0.87. Thus, indicating that the minima and maxima hours presented in the predictive curve for PkT<sub>eccH</sub>150°·s<sup>-1</sup> are strong. PkT<sub>eccH</sub>60°·s<sup>-1</sup> and PkT<sub>eccH</sub>300°·s<sup>-1</sup> predictive curve also shows good predictive strength for the minima and maxima hours in the curve.

Displayed below are the results displaying the effects of soccer specific fatigue of the hamstring muscle group on player's (n = 18) dominant leg  $^{\circ}\text{P}kT_{\text{eccH}} 60^{\circ}\cdot\text{s}^{-1}$ ,  $^{\circ}\text{P}kT_{\text{eccH}}150^{\circ}\cdot\text{s}^{-1}$ ,  $^{\circ}\text{P}kT_{\text{eccH}}300^{\circ}\cdot\text{s}^{-1}$  (figure 5.3).

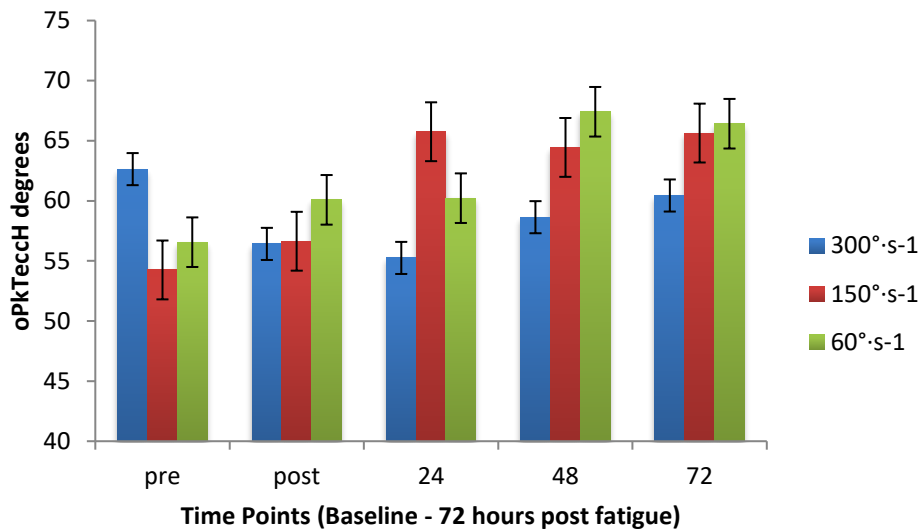


Figure 5.3: Temporal Pattern of Mean  $^{\circ}\text{P}kT_{\text{eccH}}$  Values over a 72 hr Period Post Soccer Specific (SAFT<sup>90</sup>) Fatigue at Isokinetic Speeds of  $60^{\circ}\cdot\text{s}^{-1}$ ,  $150^{\circ}\cdot\text{s}^{-1}$  and  $300^{\circ}\cdot\text{s}^{-1}$  with Standard Error ( $\pm$  SE)

Results from  $^{\circ}\text{P}kT_{\text{eccH}}$  measures highlighted that at the slow test speed of  $60^{\circ}\cdot\text{s}^{-1}$  analysis of variance showed that there were no significant differences ( $P \geq 0.05$ ) at any time points when compared to baseline. No significant differences ( $P \geq 0.05$ ) were found at any time point when compared against baseline at the testing speed of  $150^{\circ}\cdot\text{s}^{-1}$ . At the final fast testing speed of  $300^{\circ}\cdot\text{s}^{-1}$  no significant differences ( $P \geq 0.05$ ) between any of the time periods were found when compared to baseline. A significant difference ( $P \leq 0.05$ ) was highlighted between baseline and 24 hr post fatigue. Mean scores indicating a decrease in angle from baseline =  $62.64 \pm 11.80$  to 24 hr post =  $55.25 \pm 10.21$ . Polynomial regression analysis was not completed within  $^{\circ}\text{P}kT_{\text{eccH}}$  due to the lack of significant effect fatigue had on change of angle.

### 5.3.2 Dynamic Stability:

Below are the results displaying the effects of localised fatigue of the hamstring muscle group on player's (n = 18) dominant leg OSI, A-P and M-L dynamic stability scores (figure 5.4(a)).

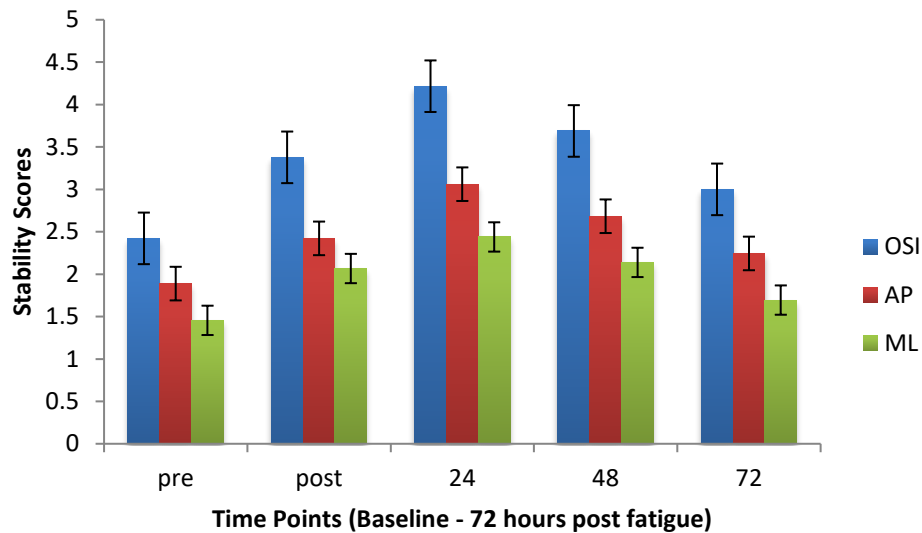


Figure 5.4(a): Temporal Pattern of Mean Dynamic Stability Values over a 72 hr Period Post Soccer Specific (SAFT<sup>90</sup>) Fatigue with Reference to OSI, A-P and M-L with Standard Error ( $\pm$  SE)

The OSI post an analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except when comparing baseline to 72 hr post fatigue ( $P \geq 0.05$ ). However, mean scores indicated that at 72 hr post fatigue, those scores still had not returned to baseline levels (baseline =  $2.42 \pm 1.07$  and 72 hr post =  $3.00 \pm 1.48$ ). Significant differences ( $P \leq 0.05$ ) were also found for the time periods 24 hr post fatigue ( $4.22 \pm 1.58$ ) to 72 hr post fatigue ( $3.00 \pm 1.48$ ). Analysis of variance for A-P presented significant findings ( $P \leq 0.05$ ) for all time periods when compared to baseline values. Significant differences ( $P \leq 0.05$ ) were also found for the time periods 24 hr post fatigue ( $3.06 \pm 1.06$ ) to 72 hr post fatigue ( $2.24 \pm 1.29$ ). The M-L post an analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except when comparing baseline to 72 hr post fatigue ( $P \geq 0.05$ ). Mean scores indicated that at 72 hr post fatigue, that scores still had not returned to baseline levels (baseline =  $1.46 \pm 0.49$  and 72 hr post =  $1.69 \pm 0.52$ ). Significant differences ( $P \leq 0.05$ ) were also found for the time

periods 24 hr post fatigue ( $\bullet 2.44 \pm 0.94$ ) to 72 hr post fatigue ( $\bullet 1.69 \pm 0.52$ ). On observation of the mean scores for OSI, A-P and M-L it can be seen that there is very little change in dynamic stability values when comparing time points 24 hr post fatigue and 48 hr post fatigue (OSI: 24 hr post fatigue =  $4.22 \pm 1.58$  and 48 hr post fatigue =  $3.69 \pm 1.62$ , A-P: 24 hr post fatigue =  $3.06 \pm 1.06$  and 48 hr post fatigue =  $2.68 \pm 1.15$  and M-L: 24 hr post fatigue =  $2.44 \pm 0.94$  and 48 hr post fatigue =  $2.14 \pm 0.85$ ).

Displayed below is the quadratic regression analysis (Figure 5.4(b)) completed for dynamic stability scores (n = 18). The curves presented represent OSI, A-P and M-L stability.

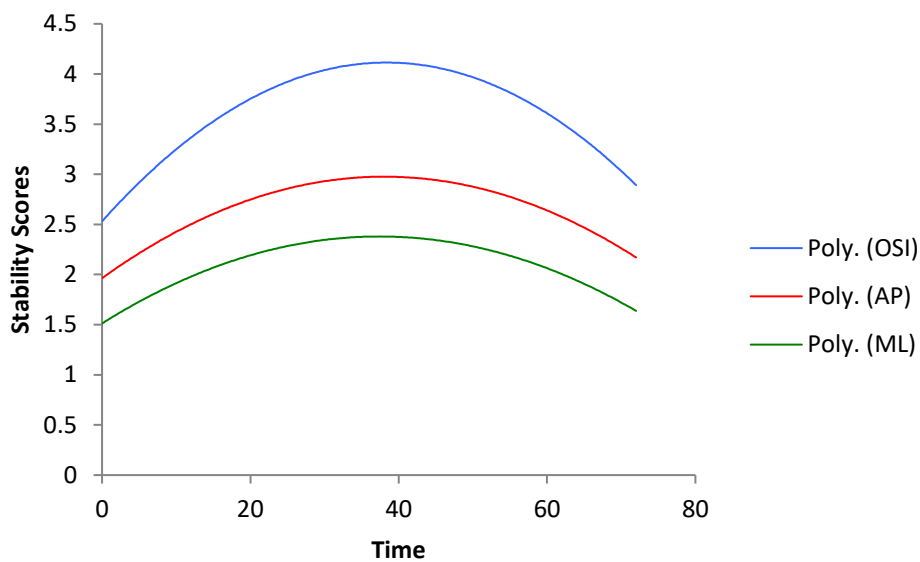


Figure 5.4(b): Quadratic Regression of Dynamic Stability Measures (OSI, A-P, M-L) Post Soccer Specific (SAFT<sup>90</sup>) Fatigue

The quadratic regression indicates that dynamic stability scores (OSI, A-P, M-L) bottom between 35 and 38 hr (OSI = 36.40 hr, A-P = 35.77 hr, M-L = 37.03 hr) and continuation of the curve indicates that they would only return to baseline levels between 76 and 82 hr (OSI = 72.80 hr, A-P = 71.54 hr, M-L = 74.07 hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 5.3.

Stability Plane	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
OSI	$y = -0.0011x^2 + 0.0826x + 2.5303$	0.87	36.40	72.80
A-P	$y = -0.0007x^2 + 0.0532x + 1.9633$	0.86	35.77	71.54
M-L	$y = -0.0006x^2 + 0.0464x + 1.5125$	0.89	37.03	74.07

Table 5.3: Displaying the r<sup>2</sup> values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves Dynamic Stability Scores of OSI, A-P and M-L

It can be seen from the r<sup>2</sup> values displayed in table 5.3 that there is a good correlation presented for all variables tested (OSI, r<sup>2</sup> = 0.87, A-P, r<sup>2</sup> = 0.86 and M-L, r<sup>2</sup> = 0.89). Thus, indicating that the minima and maxima hours presented in the predictive curve for all variables are good.

• = where significant differences were found between mean scores.

#### **5.4 Discussion:**

The aim of this study was to investigate the temporal pattern of knee flexor eccentric strength at speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup>, 300°·s<sup>-1</sup> and dynamic stability (OSI, A-P and M-L) post soccer specific fatigue. Recent research in the area has highlighted clear deficits in eccentric strength (Sangnieer et al., 2007; Greig., 2008; Small et al., 2009; Rampinini et al., 2011) and dynamic stability (Hiemstra et al., 2001; Ribeiro et al., 2010; Changela et al., 2012) as a result of fatigue. It is generally accepted that aetiological factors contributing to injury are multi factorial (Askling et al., 2003; Gabbe et al., 2006; Hewett et al., 2008; Arnason et al., 2008; Engbretsen et al., 2010; Brophy et al., 2010; Opar et al., 2012; Myer et al., 2012; Alentorn-Geli et al., 2015; Ekstrand et al., 2016) and highlighted that the main contributing factors are fatigue, eccentric strength and dynamic stability (Arnason et al., 2008; Letafatkar et al., 2009; Henderson et al., 2009; Myer et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015; Ekstrand et al., 2016). Thus, monitoring the two in conjunction and analysing the temporal pattern of each post fatigue

will detail each factors potential contribution to injury and contribute to providing justification of an athlete's likelihood of sustaining a hamstring or ACL injury.

The SAFT<sup>90</sup> soccer specific fatigue protocol utilised within this study was a free running protocol that replicated the demands of a 90 minute football match (Small et al., 2009) and incorporated several movement patterns, such as turning, side stepping, various speeds of backwards and forwards movements over a 20m course (see 3.3.3(b)). Findings from the previous study indicated that the hamstring muscle, when fatigued through a localised protocol, elicited similar acute responses to fatigue as highlighted by Greig., (2008). It also highlighted that the post fatigue it took 72 hr for slow eccentric strength and M-L dynamic stability to return to baseline measures. All other components measured had not recovered at 72 hr post fatigue; thus, indicating and implicating that the athletes have an increased chance of sustaining an injury (see chapter 4.5). The present study was completed to see if similar patterns were elicited with a soccer specific fatigue protocol, which incorporated the use of multi joint and muscle when performing.

#### ***5.4.1 Eccentric Strength:***

Results displayed show that there were significant strength decreases at all testing speeds as a result of soccer specific fatigue. Acute effects of fatigue were consistent with the findings of previous research (Pincivero et al., 2000; Willems et al., 2002; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009) and dynamic stability (Hiemstra et al., 2001; Ribeiro et al., 2008; Torres et al., 2010) and the previous study (chapter 4). Deficits in strength measures at all testing speeds ( $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ) were exhibited throughout the 72 hr temporal pattern when analysing mean scores (see figure 5.1(a) and 5.2(a)) and significant differences were displayed between baseline and the subsequent time points post fatigue. Predictive curves of recovery created from the polynomial analysis indicated that the baseline measures at all speeds would have returned at 82 hr. This prediction again emphasises its importance in injury prevention, as it could be utilised to highlight a player's readiness within periods of fixture congestion, but also guide recovery and training methods. It was also noted that completion of a post analysis of variance highlighted significant differences at the testing speed of  $PkT_{eccH}300^{\circ}\cdot s^{-1}$  between time points post fatigue and 24 hr post and 24 hr post fatigue to 72 hr post. These findings indicated a significant dip in  $PkT_{eccH}$  measures at 24 hr post fatigue and that at 72 hr post these measures were on the rise, but not fully recovered when



compared to baseline. The polynomial regression analysis indicated that strength scores hit their lowest point at 41 hr. Mean scores indicated that for AvgPkt<sub>eccH</sub> and Pkt<sub>eccH</sub> at all speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup> there were very little differences between 24 hr and 48 hr post fatigue when compared against each other. These findings emphasise that minimal recovery was taking place within this 24 hr period post fatigue and again potentially identifies a key window for intervention strategies to try to accelerate this recovery.

Findings also indicated that there were no significant changes in °Pkt<sub>eccH</sub>. When analysing figure 7.3 it can be seen the angle slightly increases and peaks at 24 hr post fatigue and then remains at this level for the remainder of the 72 hr. This change in angle is interesting, and although not significant, still indicates that these increases in angle suggest that the muscle hits its peak torque at around mid-range and thus could potentially be weakening end of range where it would become more vulnerable to injury. These findings were consistent with Small et al., 2009 and Small et al., 2010. They highlighted a reduction in hamstrings length post the SAFT<sup>90</sup> through kinematic analysis and increase in °Pkt<sub>eccH</sub> post soccer specific fatigue. This lengthened position of the hamstrings is closely associated with sustaining a muscle injury and the one most closely associated with the mechanism of injury (Opar et al., 2012; Orchard et al., 2012; Ekstrand et al., 2016). This is also significant within game play as decreased eccentric hamstrings strength end of range and when performing functionally, may make the knee more susceptible to anterior forces being exerted through it in periods of deceleration. The hamstrings are a key stabilising muscle and if it cannot withstand the load it is being subjected to then the ACL potentially is exposed (Walden et al., 2011; Hewett et al., 2013; Kim et al., 2016).

#### ***5.4.2 Dynamic Stability:***

Analysis of dynamic stability scores were consistent with previous research (Riberio et al., 2008; Riberio et al., 2010; Gear 2011; Changela et al., 2012) and showed that significant differences were displayed for all time points post fatigue when compared to baseline for A-P. OSI and M-L exhibited reductions post fatigue. No significant differences were found between baseline scores and 72 hr post; thus, indicating that these measures had recovered. Interestingly the findings in the present study were similar to those in chapter 5. It is important to acknowledge that OSI scores are dictated by a combination of A-P and M-L stability and any increase or decrease of these scores will affect the OSI output produced. This draws attention

to the discussion to M-L and A-P results and why these differences are elicited as a result of fatigue.

Mean scores throughout the temporal pattern post fatigue display that the M-L scores are consistently lower than the stability scores displayed by A-P. Cadaver evidence has shown that the mechanoreceptors within the ACL are reduced compared to other structures in the knee and it is suggested that this may contribute to the reduction in A-P stability (Zimny.,1988; Hogervorst et al., 1998; Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009). Analysis of the mean scores show that the A-P baseline measures are also higher than the M-L stability scores (1.89 compared to 1.46); thus, potentially supporting the thought that the decreased mechanoreceptors contained within the ACL do not provide as an effective response as those within the medial and lateral structures of the joint.

Injury within the joint or to a muscular structure has been associated with an EMD and findings from the present study suggest that A-P stability is experiencing this EMD above that displayed through M-L. This would suggest that the ACL and the hamstring muscle could therefore be exposed to an increased chance of injury. Potential debate exists to why this EMD occurs. One suggestion is that it could be due to the scarcity of the mechanoreceptors within the ACL and this results in an increased load through the joint (Zimny 1988; Hogervorst et al., 1998). Alternatively, it could be that the fatiguing biproducts result in the desensitisation of the intrafusal fibres within the muscle and this results in a delayed response (Riberio et al., 2008; Riberio et al., 2010; Torres., et al 2010). The significance of what is causing the EMD is difficult to ascertain and arguably unimportant. Any research into the efficiency of mechanoreceptor function, afferent and efferent pathways would be highly invasive. The most important conclusion to be drawn from the findings from the present study is that neuromuscular function is decreased as a result of fatigue and this reduction is more prevalent in A-P stability. Clearly there is a link between a reduction in eccentric strength and dynamic stability, the results from this study allow more specific conclusions to be drawn. It is clear that the reduction in functional hamstring strength will contribute to the decrease in dynamic stabilisation and more specifically A-P stability. These findings support current literature in the field and the approach that ACL and hamstring injuries are multi factorial (Askling et al., 2003; Hoskins., 2005; Pizzari et al., 2010; Mendiguchia et al., 2011; Opar et al., 2012) and specifically highlight the significance of fatigue, eccentric strength and dynamic stability.

### 5.4.3 Synopsis:

Comparisons of the temporal patterns post fatigue of eccentric strength and dynamic stability emphasise the relationship between functional hamstrings strength and A-P stability. It can be seen that both elicit continuous reductions from baseline, which are predicted to hit their lowest point at 36 - 41 hr post fatigue. Eccentric strength and A-P stability are still depleted at 72 -82 hr when as highlighted in the predictive quadratic regression analysis. These findings are consistent with those in chapter 4 when the hamstring was exposed to localised fatigue and the 72 hr temporal pattern monitored. The acute effects of fatigue are similar to the findings of previous research (Greig., 2008; Greig et al., 2009; Small et al., 2009; Small et al., 2010) and can provide explanation to why players are sustaining hamstring and ACL injuries within game play, which are potentially greater during periods of fixture congestion. The bigger picture of the modern game is the cumulative effect of fatigue and readiness of players for the following fixture, which players can be exposed to regularly within a 72 hr period. The findings of the current study highlight the potential for injury if an effective intervention is not applied to increase or accelerate the recovery of functional strength and dynamic stability.

Comparisons can be made from the results obtained in the current chapter to the findings in chapter 4 where hamstrings were locally fatigued. Recovery of all variables of eccentric strength and dynamic stability following the localised fatigue protocol ranged from 76.05 hr to 82.03 hr when analysing the predictive curve from the quadratic regression completed, with the exception of  $PkT_{eccH150^{\circ}\cdot s^{-1}}$ . The variables of eccentric and dynamic stability in the present study ranged from 72.87 – 81.23, which the exception of  $AvgPkT_{eccH150^{\circ}\cdot s^{-1}}$  and A-P stability. The small differences found within hr maybe attributed to different sets of players being used for analysis within each study and if the same players were utilised for both studies this may have changed this outcome. Conclusions drawn from comparisons and analysis of the temporal patterns of recovery post fatigue in both protocols indicate that after local or soccer specific fatigue, deficits are exhibited in function in relation to eccentric strength and dynamic stability. This finding supports current research in the field that indicates specific eccentric loading of muscle groups and particularly the hamstrings can elicit significant fatigue effects (Marshall et al., 2015). It also highlights the significance fatigue has on the function of the hamstring muscle group in isolation, and these deficits are comparable to when performing and utilising multi-joint movements. Further research in the area and key to guiding periodised planning within a

season would be to look at whether plyometrics or specific strength training elicited similar responses post.

The findings from this study clearly support those in chapter 4 and highlight the importance of the hamstring muscles in stabilisation of the knee joint and also that fatigue has a clear effect on the hamstring muscles and function. This reduction in function as a result of soccer specific fatigue has previously focussed on the acute effects. Conclusions drawn from this study clearly highlight the importance of the potential cumulative effects of fatigue on increasing a player's possibility of sustaining injury, in relation to eccentric strength and dynamic stability. These findings emphasise the importance of careful implementation of intervention strategies and any intervention has to be focussed on accelerating recovery within the 24-48 hr-post fatigue window to ensure players are fully recovered in time for the next fixture. They also highlight the importance of consideration of types of training post-game play within this 72 hr period and the need to utilise this information to inform periodised plans. In addition to this there is potential to utilise these biomechanical measures as a tool to monitor player's progression through rehabilitation and carefully implement these measures within their return to play criteria post hamstring or ACL injury.

## **5.5 Conclusion:**

$PkT_{eccH}$ ,  $AvgPkT_{eccH}$  and dynamic stability measures of OSI, A-P and M-L were observed to deteriorate post soccer specific fatigue and remained low for a period of 72 hr post fatigue. The only exceptions to this were at 72 hr no effect was found for OSI and M-L dynamic stability measures. There was also no effect identified for angle of peak torque measures post fatigue throughout the temporal measures up to 72 hr post. Mean differences showed an increase in angle, which peaked at 24 hr post fatigue. The significance of these findings highlight that the athlete could be more susceptible to injury through explosive movements at any point within the 72 hr period, where they may be expected to train or play again post fatigue. It also highlights that the proprioceptive response is depleted for up to a 72 hr period for movement through an A-P plane, thus highlighting the potential to expose the ACL to more stress. This indicates that the measures of eccentric strength and A-P dynamic stability are useful markers to be utilised as predictors of injury, but also that there is a need to develop hamstrings strength endurance to increase stability of the knee through performance and also make them resistant to muscular strain. Similar findings can be seen when comparing the effects of localised fatigue

(chapter 4) and soccer specific fatigue in relation to the temporal pattern and the acute effects of fatigue. Emphasising that any loading to the hamstring muscle group whether local or soccer specific results in a reduction in biomechanical function and can potential indicate a player's susceptibility to injury between games within a period of fixture congestion.

## **Chapter 6: The Efficacy of Soft Tissue Therapy on the Temporal Recovery of Eccentric Hamstrings Strength and Dynamic Stability**

### **6.1 Introduction:**

Sports massage is defined as a form of soft tissue mobilisation/manipulation of muscle with varying pressures, for the purpose of promoting an individual's health and wellbeing (Galloway et al., 2004). There are various forms of massage technique utilised in the field and they are known as effleurage, petrissage, tapotment, frictions and vibratory. Each of the techniques has their own claims to the physiological effects and their uses within practice, but the most commonly used techniques within sport for player recovery post fatigue are effleurage and petrissage. These techniques claim to elicit an increased blood flow by warming the tissues and encourage lymphatic drainage to the area, which aids the removal of fatiguing bi-products built up through game play (Ernst 1998; Zainuddin et al., 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014), although conflicting evidence throughout literature questions if this is the case (Wiltshire et al., 2010). Nedelec et al., (2013) emphasises within their review of the literature surrounding massage that the skills of the therapist within this field and the choice of massage technique utilised, as a recovery tool could be one of the main reason for inconsistencies within findings and this should be addressed within future studies. It is also important to note that nowhere within literature is it indicated when massage should be implemented post fatigue as a recovery tool to improve muscle function. Indicating that if implemented at the right stage within the recovery process post fatigue, then this may accelerate recovery in relation to muscle function.

A prominent reason for use of sports massage within clubs is to aid and accelerate a player's recovery. The proposed physiological benefits of this are associated with lactate clearance post exercise, a decrease in DOMS and a reduction in muscle fatigue (Moraska., 2005). Lactate clearance and fatigue are associated with the effective use of effleurage within practice. Effleurage can be administered in two ways through superficial strokes or deeper strokes through the tissue. Shoemaker et al., 1997 and Hinds et al., 2004 dispute claims that effleurage increases circulation and actually dispute if there are any effects on circulation through the tissue at all. However, it is extremely important to note that the type of techniques utilised within effleurage and the experience of the clinicians used to administer the sports massage

within each paper is questionable, as none of the literature listed states the experience or type of clinician administering the treatment modality. This raises the argument that if the clinician utilised was of a significant skill set and had a specialism in the area would this have changed the outcome of these results. Therefore, proposing that until an appropriately experienced clinician is utilised with a high enough skill set then the physiological benefits to sports massage cannot be discounted, nor can it be rejected as an ineffective tool for recovery. This is supported by current practice within football, as within all medical departments within the elite level have access to masseurs and they monitor players use of this as a recovery tool.

Arguably delayed onset muscle soreness (DOMS) is a major contributory factor to decreased muscle function post fatigue (Clarkson et al., 1992; Cheung et al., 2003). Both the aforementioned papers highlighted deficits within eccentric hamstrings strength between 24 – 48 hours and attributed this to DOMS. Highlighting, that when eccentric exercise is undertaken it can take between 8 – 10 days. Essentially, this recovery period will be based on the physiological efficiency of the individual's bodily function, but also their state of conditioning, as none of the subjects utilised within these studies were athletes. It is key to note that DOMS can have a detrimental effect on the muscle function and the extent of the DOMS will be positively correlated to the amount of eccentric load the athlete has experienced. It is known that after extensive loading there is a release of histamines and prostaglandins, which are chemicals associated with an inflammatory response and it is these compounds or this reaction of the muscle tissue that has been attributed as the resultant pain response post exercise. Interestingly the limited research published in this area predominantly supports the use of massage and highlights that a sports massage utilised to combat the effects of DOMS, should last no longer than 10 minutes per body region, consisting of effleurage and petrissage strokes (Mosaka, 2005). There is little suggestion within this published literature the time course effect of administering the massage is and there is a definitive gap suggesting that post treatment the athlete should then be monitored in relation to their recovery period, to determine the effectiveness of the massage. The importance of establishing this cannot be overstated, as it will detail to clinicians, coaches and medical teams the optimal time for an athlete to get a sports massage completed and clearly highlight where this needs to be administered in a player's recovery protocol.

Commonly in football, players can be subjected to periods of fixture congestion, which results in them playing a succession of games within a period of 7 days or more specifically need to be ready to play again within a 72-hour time frame. Evidence has suggested that the bi-products produced by the body as a result of fatigue can desensitise the afferent and efferent nerve pathways at source of the mechanoreceptors, thus effecting how a muscle can respond to the demands being placed upon it (Johnston et al., 1998; Changela et al., 2012). This creates an issue for the athlete and would link to why injuries are increased in certain periods of the year when fixture congestion is an issue (Carling et al., 2015), but also why athletes are more susceptible to injury in the later stages of each half of the game (Greig., 2008; Greig et al., 2009; Small et al., 2009). Highlighting, the importance of identifying the temporal pattern post fatigue and establishing whether common methods utilised for recovery like sports massage are advantageous and when they should be implemented.

Evidence conclusively identifies that a decrease in eccentric hamstrings strength is associated with muscle injury (Mair et al., 1996; Askling et al., 2003; Arnason et al., 2008; Greig, 2008; Small et al., 2009; Delextrat, 2010; Engbretsen et al., 2010; Ekstrand et al., 2011; Mackey et al., 2011; Petersen et al., 2011; Opar et al., 2012) and this reduction in strength can also increase the chance of the knee sustaining a serious injury due to the decrease in dynamic stability. It is unclear what causes this decrease in strength, but there are suggestions those neuromuscular afferent and efferent pathways, particularly the muscle spindles/golgi tendon organs are desensitised as a result of fatigue (Changela et al., 2012). Shin et al., (2015) concluded from their research that massage post exercise induced muscle damage increased proprioceptive control and decreased strength deficits experienced post fatigue within the gastrocnemius and this was attributed to the massage. They highlighted that recovery massage should last no longer than ten minutes to facilitate the removal of lactate, ammonia and oxypurines and further evidence indicates that the timing of the massage, type of massage and type of exercise completed can influence its effectiveness (Nelson., 2013). It is noted that the massage was introduced immediately after exercise and a greater understanding of the temporal pattern of eccentric hamstrings strength and dynamic stability would detail where it should be implemented to maximise the potential benefits within recovery. In addition to this a physiotherapist carried out the massage, but there was no indication of their level of experience; thus raising the question would a more experienced clinician/specialist in this area elicited greater recovery.



Given the nature of the current evidence surrounding massage and the effectiveness of it as an intervention strategy to decrease injury, the present study was designed to investigate the effects a 15-minute sports massage has on the temporal pattern of eccentric strength and dynamic stability post soccer specific fatigue. It is proposed that the massage will be implemented at 24 hr post soccer specific fatigue due to the plateau experienced within markers of recover between 24-48 hr (Clarkson et al., 1992; Cheung et al., 2003). By implementing a sports massage at this stage the study is identifying whether the intervention employed speeds up this process and returns players quickly back to baseline levels. A clinician with a minimum of 10 year's experience as a soft tissue specialist within elite sport undertook the sports massage on each player, as evidence definitively details depth and technique of the massage determines its effectiveness (Petrofsky et al., 2008; Tew et al., 2010; Mori et al., 2014; Caldwell et al., 2016). Recovery was quantified by measures of eccentric hamstrings PkT, AvgPkT and °PkT, accompanied with measures of dynamic stability, with the temporal pattern of these being tracked for 72 hr. The significance of this research cannot be overstated, as it will advise clinician's and medical departments of the impact of sports massage as a recovery tool. Tus, underlining its effectiveness in relation to two key markers of injury, but also when the most appropriate time for implementing this strategy would be.

## **6.2 Methodology:**

### ***6.2.1 Participants:***

Fourteen male professional soccer players completed the present study, with a mean age and SD of  $24.29 \pm 5.06$  years, height  $184.51 \pm 3.91$  cm and body mass of  $74.91 \pm 4.30$  kg. All participants were screened to ensure suitability for the study in relation to inclusion/exclusion criteria (3.2.2) and provided written informed consent in accordance with the department and university ethical procedures as listed in the general methodology (3.2.1). In addition to the inclusion/exclusion criteria all participants were subjected to an allergy test against the medium used for the massage. This test was administered by applying the medium to the thenar eminence and left for 5 minutes to assess any reaction to the medium. If any player reacted to the medium they were subsequently excluded from the investigation.

### **6.2.2 Experimental Design:**

Before completion of the familiarisation and testing protocols, all players in the study were subjected to the appropriate anthropometric measures outlined in the general methodology (3.3). On completion of the relevant checks and consent being obtained players were then asked to complete a warm up, which consisted of 10 mins of the SAFT<sup>90</sup> protocol (3.3.3(b)). Post completion of the warm up participants were supervised through a series of dynamic stretches, which included the hamstrings, quadriceps, adductors, abductors and gastrocnemius. The stretches were completed for 12 repetitions within a 30 second period and this was consistent for all participants (Herda et al., 2008; Page, 2012). Static stretching was not considered as it has been shown to have a negative effect on dynamometer-measured strength (Herda et al., 2008; Siatras et al., 2008; Sekir et al., 2010; Page, 2012). This was carried out before completion of any familiarisation or testing protocols. Familiarisation trials were then completed for the soccer specific fatigue protocol, IKD testing and BSS testing (3.3.3(b) and 3.3.1 and 3.3.2).

Post the familiarisation trials testing could proceed. Players were invited back to the laboratory 7 days' post familiarisation testing and completed measures on the IKD and BSS, the testing protocols for each are detailed in the general methodology (3.3.1 and 3.3.2). Post obtaining baseline scores the players were then subjected to the soccer specific fatigue protocol (3.3.3(b)). During completion of the fatigue protocol Borg's (1970) 6-20 point scale was used to record the participant's subjective rating of perceived exertion and was recorded at rest and post each 15 minute period of the SAFT<sup>90</sup>. In addition to this heart rate (HR) was also recorded every 15 minutes during each trial of the fatigue protocol using a HR monitor (Polar, Team system, Finland). Attendance time was noted for each player with regards baseline measures and the soccer specific fatigue protocol and for the subsequent time points to monitor the temporal pattern post fatigue, they were asked to return at exactly the same time (Drust et al., 2005). To monitor the temporal pattern of recovery of the athlete and the effect soft tissue massage has on this period IKD and BSS measurements were taken immediately post fatigue, 24 hr post fatigue and pre massage, 24 hr post fatigue and post massage, 48 hr and 72 hr post fatigue, again all measurements were consistent with testing procedures detailed in the general methodology (3.3.1 and 3.3.2). The data analysis applied to the soccer specific fatigue protocol with the intervention of soft tissue massage was consistent with chapter 3.4 of the General Methodology.

### ***6.2.3 Soft Tissue Massage Application:***

A Sports Therapist who was currently working within elite sport and with 11 years experience at this level completed the soft tissue massage on all participants at time point 24 hr post fatigue. Massage was completed on both limbs. Pre massage IKD and BSS measures were taken and these were also then completed immediately post massage, again following protocols listed in the general methodology (3.3.1 and 3.3.2). A combination of effleurage and petrissage techniques (Mori et al., 2014; Caldwell et al., 2016) were applied by the therapist immediately post fatigue for a period of 20 mins on the each limb. The focus of the effleurage techniques was applied to the gastrocnemius, hamstring and gluteals musculature. Effleurage techniques were applied at the beginning of the soft tissue massage for 5 minutes across the musculature listed and consisted of lighter strokes with minimal depth. This was followed by petrissage being applied for a period of ten minutes across the musculature listed with a heavier focus on the hamstrings, consisting of deeper techniques and strokes. The soft tissue therapy was then completed by applying 5 mins effleurage, which was consistent with the opening 5 minutes of the therapy applied, consisting of lighter strokes through the muscle tissue. No one area of the limb was treated for longer than a ten min period and all massage was performed from distal extremities to proximal. To ensure that the intensity of the massage pressure remained above pain thresholds, the therapist was in constant communication with the player with regards pain sensation and perception of pain from the techniques applied.

### ***6.2.4 Statistical Analysis:***

The  $PkT_{eccH}$ ,  $AvpPkT_{eccH}$  and  ${}^{\circ}PkT_{eccH}$  for all 3 testing speeds and dynamic stability outcome measures of OSI, A-P and M-L were determined at baseline, post soccer specific fatigue and at consistent time points at 24 hr post fatigue and pre massage, 24 hr post fatigue and post massage, 48 hr and 72 hr post fatigue. Tests for outliers, to identify if the data was normally distributed and sphericity, for equal variance in the data, were then completed, as detailed in chapter 3.5 of the general methodology. The data was then analysed using a one way repeated measures analysis of variance (ANOVA) for each output measure to establish whether there were significant differences between the base line values and the testing periods post fatigue, 24 hours post fatigue and pre massage, 24 hr post fatigue and post massage, 48 hr and 72 hr post fatigue, determining if there was a significant main effect for recovery time. All statistical analysis was performed using PASW Statistics Editor 18.0 for windows (SPSS Inc, Chicago,

USA) with an accepted significance level set at  $P \leq 0.05$  (3.5). Quadratic regression analysis was completed as described in the general methodology (3.5).

### 6.3 Results:

#### 6.3.1 Eccentric Strength:

Below are the results displaying the effects of soccer specific fatigue on the hamstring muscle group of player's ( $n = 14$ ) dominant leg  $\text{AvgPkT}_{\text{eccH}60^\circ \cdot \text{s}^{-1}}$ ,  $\text{AvgPkT}_{\text{eccH}150^\circ \cdot \text{s}^{-1}}$ ,  $\text{AvgPkT}_{\text{eccH}300^\circ \cdot \text{s}^{-1}}$  (figure 6.1(a)).

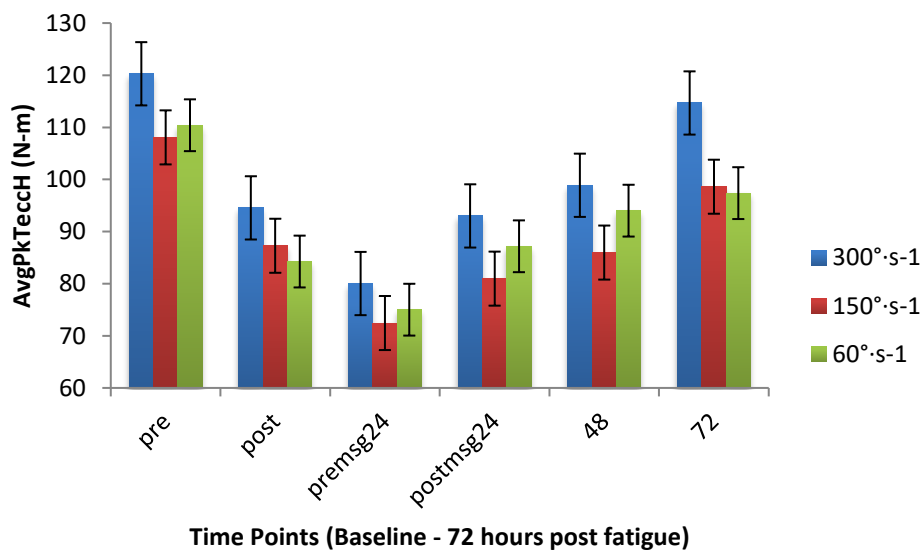


Figure 6.1(a): Temporal Pattern of Mean  $\text{AvgPkT}_{\text{eccH}}$  Values over a 72-hour Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with an Intervention of Soft Tissue Massage at Isokinetic Speeds of  $60^\circ \cdot \text{s}^{-1}$ ,  $150^\circ \cdot \text{s}^{-1}$  and  $300^\circ \cdot \text{s}^{-1}$  with Standard Error ( $\pm$  SE)

At the slowest test speed ( $60^\circ \cdot \text{s}^{-1}$ ) for  $\text{AvgPkT}_{\text{eccH}}$  analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except at 72 hr post, where no significant effect was found ( $P \geq 0.05$ ). Significant differences ( $P \leq 0.05$ ) were also identified within several time points. These include post fatigue ( $84.25 \pm 18.89 \text{N} \cdot \text{m}$ ) to 48 hr post fatigue ( $94.01 \pm 18.51 \text{N} \cdot \text{m}$ ); post fatigue ( $84.25 \pm 18.89 \text{N} \cdot \text{m}$ ) to 72 hr post fatigue ( $97.38 \pm 19.18 \text{N} \cdot \text{m}$ ), 24 hr post fatigue before massage was applied ( $75.01 \pm 14.28 \text{N} \cdot \text{m}$ ) to 24 hr post fatigue post massage application ( $87.18 \pm 17.90 \text{N} \cdot \text{m}$ ), 24 hr pre massage application

(75.01±14.28N•m) to 48 hr post fatigue (94.01±18.51N•m), 24 hr post fatigue and pre massage application (75.01±14.28N•m) to 72 hr post fatigue (97.38±19.18N•m) and 24 hr post fatigue and post massage application (87.18±17.90N•m) to 72 hr post fatigue (97.38±19.18N•m). Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of  $150^\circ \cdot s^{-1}$ , except at 72 hr where no significant effect was found ( $P \geq 0.05$ ). Significant differences ( $P \leq 0.05$ ) were also found within time points; post fatigue (87.28±22.48N•m) to 72 hr post (98.60±23.98N•m), 24 hr post fatigue and pre massage (72.46±17.74N•m) to 72 hr post (98.60±23.98N•m), 24 hr post fatigue and post massage (80.97±15.65N•m) to 72 hr post (98.60±23.98N•m) and 48 hr post (85.97±23.07N•m) to 72 hr post (98.60±23.98N•m). Similar results at the final fast testing speed of  $300^\circ \cdot s^{-1}$  also displayed significant differences ( $P \leq 0.05$ ) between all time periods when compared to baseline, except baseline to 72 hr where no significance was found ( $P \geq 0.05$ ). Significant differences ( $P \leq 0.05$ ) were also found between time points; post fatigue (94.55±26.46N•m) to 24 hr post fatigue and pre massage (80.03±20.42N•m); post fatigue (94.55±26.46N•m) to 72 hr post (114.67±27.55N•m); 24 hr post fatigue and pre massage (80.03±20.42N•m) to 48 hr post (98.88±23.94N•m); 24 hr post and pre massage (80.03±20.42N•m) to 72 hr post (114.67±27.55N•m); 24 hr post fatigue and post massage (93.00±20.59N•m) to 72 hr post (114.67±27.55N•m) and 48 hr post (98.88±23.94N•m) to 72 hr post (114.67±27.55N•m).

Displayed below is the quadratic regression analysis (Figure 6.1(b)) completed for AvgPkJ<sub>eccH</sub> (n = 14). The curves presented represent AvgPkJ<sub>eccH</sub>60°·s<sup>-1</sup>, AvgPkJ<sub>eccH</sub>150°·s<sup>-1</sup>, AvgPkJ<sub>eccH</sub>300°·s<sup>-1</sup>.

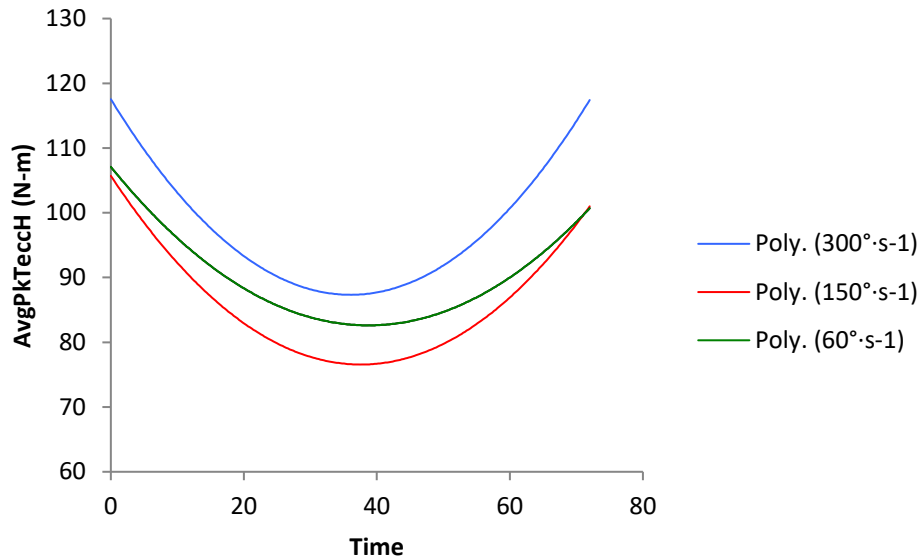


Figure 6.1(b): Quadratic Regression of AvgPkJ<sub>eccH</sub> Post Soccer Specific Fatigue with an Intervention of Soft Tissue Massage at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup>

The quadratic regression indicates that AvgPkJ<sub>eccH</sub> values between 26 and 31 hr (300°·s<sup>-1</sup> = 33.81 hr, 150°·s<sup>-1</sup> = 35.18 hr, 60°·s<sup>-1</sup> = 26.59 hrs and continuation of the curve indicates that they would only return to baseline levels between 53 and 71 hours (300°·s<sup>-1</sup> = 67.61hrs, 150°·s<sup>-1</sup> = 70.37hrs, 60°·s<sup>-1</sup> = 53.19hrs). The quadratic regression equation, r<sup>2</sup> values and the minima and maxima hours of the curve can be seen below in Table 6.1.

Isokinetic Speed	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
300°·s <sup>-1</sup>	y = 0.0233x <sup>2</sup> - 1.6766x + 117.55	0.81	33.81	67.61
150°·s <sup>-1</sup>	y = 0.0163x <sup>2</sup> - 1.2645x + 107.1	0.84	35.18	70.37
60°·s <sup>-1</sup>	y = 0.0206x <sup>2</sup> - 1.5502x + 105.7	0.64	26.59	53.19

Table 6.1: Displaying the  $r^2$  values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves AvgPkJecch at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$  and  $300^\circ \cdot s^{-1}$

It can be seen from the  $r^2$  values displayed in table 6.1 that there is a good correlation presented for variables tested AvgPkJecch $150^\circ \cdot s^{-1}$ ,  $r^2 = 0.84$  and AvgPkJecch $300^\circ \cdot s^{-1}$ ,  $r^2 = 0.81$ ). Thus, indicating that the minima and maxima hr presented in the predictive curve are good. AvgPkJecch $60^\circ \cdot s^{-1}$ ,  $r^2 = 0.64$  indicating a weak correlation between strength and time.

Displayed below are the results displaying the effects of soccer specific fatigue on the hamstring muscle group of player's (n = 14) dominant leg PkJecch $60^\circ \cdot s^{-1}$ , PkJecch $150^\circ \cdot s^{-1}$ , PkJecch $300^\circ \cdot s^{-1}$  (figure 6.2(a)).

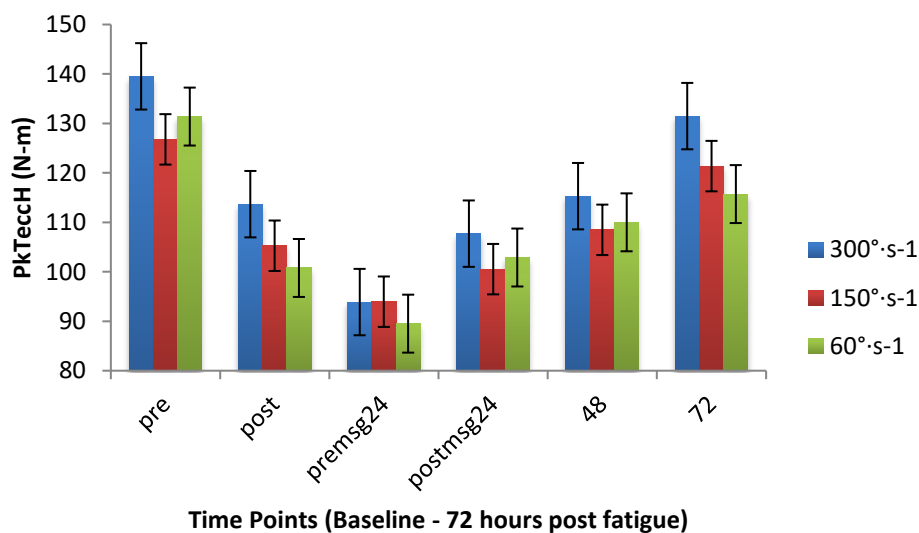


Figure 6.2(a): Temporal Pattern of Mean PkJecch Values over a 72 hr Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with an Intervention of Soft Tissue Massage at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$ ,  $300^\circ \cdot s^{-1}$  with Standard Error ( $\pm$  SE)

Results from the PkJecch measures highlighted that at the slow test speed of  $60^\circ \cdot s^{-1}$  analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except at 72 hr post, where no significant effect was found ( $P \geq 0.05$ ). Analysis of the mean scores between time points showed significant differences ( $P \leq 0.05$  for; post fatigue ( $100.77 \pm 24.14 N \cdot m$ ) to 48 hr post fatigue ( $110.00 \pm 25.27 N \cdot m$ ); post fatigue

(100.77±24.14N•m) to 72 hr post fatigue (115.72±21.57N•m); 24 hr post fatigue and pre massage (89.51±16.18N•m) to 24hours post fatigue and post massage (102.89±18.62N•m); 24 hr post fatigue and pre massage (89.51±16.18N•m) to 48 hr post fatigue (110.00±25.27N•m); 24 hr post fatigue and pre massage (89.51±16.18N•m) to 72 hr post fatigue (115.72±21.57N•m) and 24 hr post fatigue and post massage (102.89±18.62N•m) to 72 hr post fatigue (115.72±21.57N•m). Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of  $150^\circ \cdot s^{-1}$ , except at 72 hr post, where no significant effect was found ( $P \geq 0.05$ ). Significant differences were also identified between time points; post fatigue (105.27±23.87N•m) to 72 hr post (121.37±24.37N•m), 24 hr post fatigue and pre massage (93.95±18.89N•m) to 72 hr post (121.37±24.37N•m), 24 hr post and post massage (100.53±14.47N•m) to 72 hr post (121.37±24.37N•m), 48 hr post fatigue (108.48±26.44N•m) to 72 hr post (121.37±24.37N•m). Similar results at the final fast testing speed of  $300^\circ \cdot s^{-1}$  also displayed significant differences ( $P \leq 0.05$ ) between all time periods when compared to baseline, except at 72 hr post, where no significant effect was found ( $P \geq 0.05$ ). On analysis of the mean scores for this testing speed significant differences were also identified between time points; post fatigue (113.67±24.93N•m) to 72 hr post (131.48±29.06N•m), 24 hr post fatigue and pre massage (93.88±21.88N•m) to 48 hr post fatigue (115.29±25.46N•m), 24 hr post fatigue and pre massage (93.88±21.88N•m) to 72 hr post fatigue (131.48±29.06N•m), 24 hr post fatigue and post massage (107.71±22.37N•m) to 72 hr post (131.48±29.06N•m), 48 hr post fatigue (115.29±25.46N•m) to 72 hr post fatigue (131.48±29.06N•m).



Displayed below is the quadratic regression analysis (Figure 6.2(b)) completed for  $PkT_{eccH}$  ( $n = 14$ ). The curves presented represent  $PkT_{eccH}60^{\circ}\cdot s^{-1}$ ,  $PkT_{eccH}150^{\circ}\cdot s^{-1}$ ,  $PkT_{eccH}300^{\circ}\cdot s^{-1}$ .

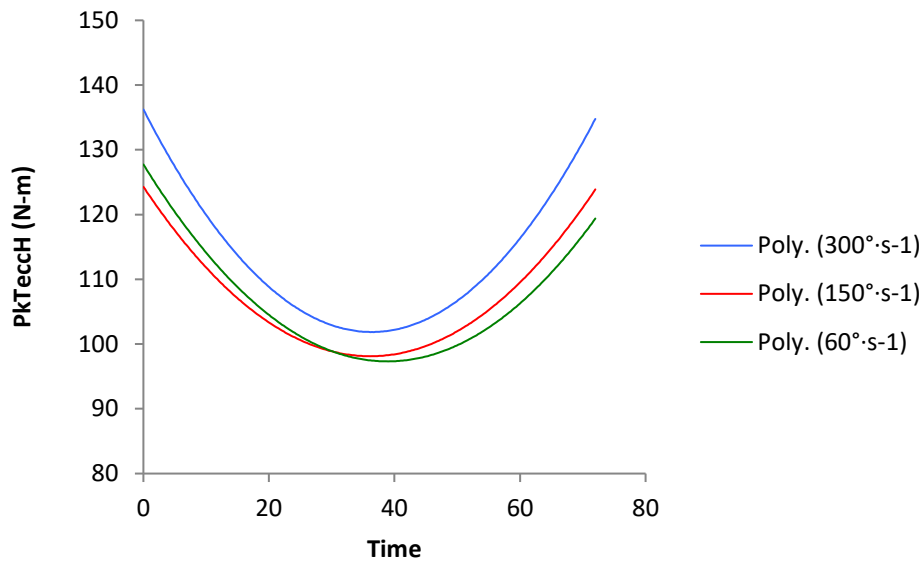


Figure 6.2(b): Quadratic Regression of  $PkT_{eccH}$  Post Soccer Specific Fatigue ( $SAFT^{90}$ ) with an Intervention of Soft Tissue Massage at Isokinetic Speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$

The quadratic regression indicates that  $PkT_{eccH}$  values between 28 and 36 hr ( $300^{\circ}\cdot s^{-1} = 33.39$  hr,  $150^{\circ}\cdot s^{-1} = 35.10$ hrs,  $60^{\circ}\cdot s^{-1} = 28.72$  hr) and continuation of the curve indicates that they would only return to baseline levels between 57 and 71 hr ( $300^{\circ}\cdot s^{-1} = 66.78$ hrs,  $150^{\circ}\cdot s^{-1} = 70.21$ hrs,  $60^{\circ}\cdot s^{-1} = 57.44$  hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 6.2.

Isokinetic Speed	Quadratic Regression Equation	$r^2$ Value	Minima in hr	Maxima in hr
$300^{\circ}\cdot s^{-1}$	$y = 0.026x^2 - 1.8889x + 136.23$	0.80	33.39	66.78
$150^{\circ}\cdot s^{-1}$	$y = 0.02x^2 - 1.4475x + 124.28$	0.84	35.10	70.21
$60^{\circ}\cdot s^{-1}$	$y = 0.0201x^2 - 1.5644x + 127.74$	0.69	28.72	57.44

Table 6.2: Displaying the  $r^2$  values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves PkT<sub>eccH</sub> at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$  and  $300^\circ \cdot s^{-1}$

It can be seen from the  $r^2$  values displayed in table 6.2 that there is a good correlation presented for variables tested AvgPkT<sub>eccH</sub> $150^\circ \cdot s^{-1}$ ,  $r^2 = 0.84$  and AvgPkT<sub>eccH</sub> $300^\circ \cdot s^{-1}$ ,  $r^2 = 0.80$ ). Thus, indicating that the minima and maxima hours presented in the predictive curve are good. AvgPkT<sub>eccH</sub> $60^\circ \cdot s^{-1}$ ,  $r^2 = 0.69$  indicating a weak correlation between strength and time.

Displayed below are the results displaying the effects of soccer specific fatigue of the hamstring muscle group on player's (n = 18) dominant leg  $^\circ$ PkT<sub>eccH</sub>  $60^\circ \cdot s^{-1}$ ,  $^\circ$ PkT<sub>eccH</sub> $150^\circ \cdot s^{-1}$ ,  $^\circ$ PkT<sub>eccH</sub> $300^\circ \cdot s^{-1}$  (figure 6.3).

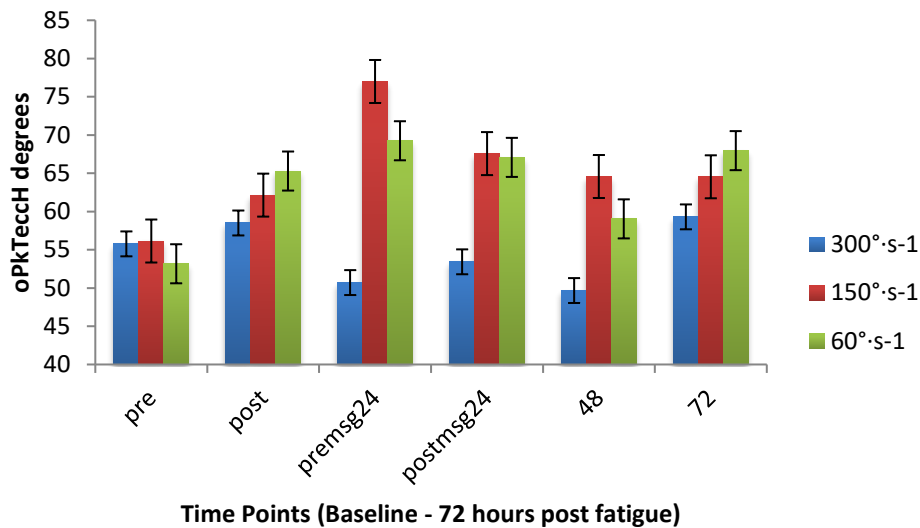


Figure 6.3: Temporal Pattern of Mean  $^\circ$ PkT<sub>eccH</sub> Values over a 72 hr Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with an Intervention of Soft Tissue Massage at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$ ,  $300^\circ \cdot s^{-1}$  with Standard Error ( $\pm$  SE)

Results from  $^\circ$ PkT<sub>eccH</sub> measures highlighted that at the slow test speed of  $60^\circ \cdot s^{-1}$  analysis of variance showed that there were no significant differences ( $P \geq 0.05$ ) at any time points when compared to baseline. No significant differences ( $P \geq 0.05$ ) were found at any time point when compared against baseline at the testing speed of  $150^\circ \cdot s^{-1}$ . At the final fast testing speed of  $300^\circ \cdot s^{-1}$  no significant differences ( $P \geq 0.05$ ) between any of the time periods were found when

compared to baseline. Polynomial regression analysis was not completed within  $^{\circ}\text{Pkt}_{\text{eccH}}$  due to the lack of significant effect fatigue had on change of angle.

**6.3.2 Dynamic Stability:**

Below are the results displaying the effects of localised fatigue of the hamstring muscle group on player’s (n = 14) dominant leg OSI, A-P and M-L dynamic stability scores (figure 6.4(a)).

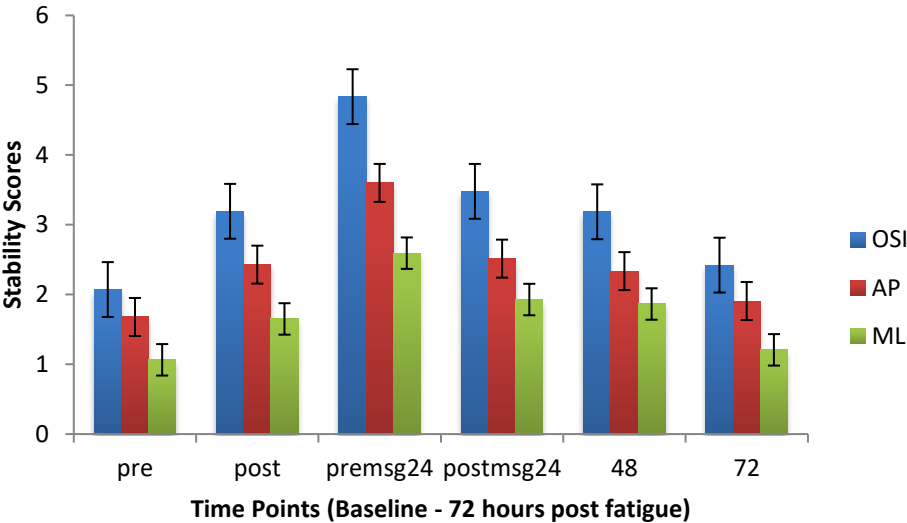


Figure 6.4(a): Temporal Pattern of Mean Dynamic Stability Values over a 72 hr Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with an Intervention of Soft Tissue Massage with Reference to OSI, A-P and M-L with Standard Error (± SE)

The OSI post an analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except between baseline and 72 hr post where no significance was found ( $P \geq 0.05$ ). It was also identified that there were notable significant differences ( $P \leq 0.05$ ) within time points through the temporal pattern post fatigue, which were found between; post fatigue ( $\bullet 3.19 \pm 1.23$ ) to 24 hr post and pre massage ( $\bullet 4.84 \pm 2.25$ ); 24 hr post and pre massage ( $\bullet 4.84 \pm 2.25$ ) to 48 hr post ( $\bullet 3.19 \pm 1.53$ ), 24 hr post and pre massage ( $\bullet 4.84 \pm 2.25$ ) to 72 hr post ( $\bullet 2.42 \pm 1.13$ ), 24 hr post and post massage ( $\bullet 3.48 \pm 1.58$ ) to 72 hr post ( $\bullet 2.42 \pm 1.13$ ), 48 hr post ( $\bullet 3.19 \pm 1.53$ ) to 72 hr post ( $\bullet 2.42 \pm 1.13$ ). Analysis of variance for A-P presented significant findings ( $P \leq 0.05$ ) for time periods post fatigue, pre massage and 24 hr post fatigue and post massage when compared to baseline values. No Significant differences

( $P \geq 0.05$ ) were found for the time periods 48 hours post fatigue and 72 hr post fatigue. Significant differences were highlighted within time points; 24 hr post fatigue and pre massage ( $\bullet 3.60 \pm 1.72$ ) to 48 hr post fatigue ( $\bullet 2.34 \pm 1.01$ ), 24 hr post fatigue and pre massage ( $\bullet 3.60 \pm 1.72$ ) to 72 hr post ( $\bullet 1.91 \pm 0.97$ ), 24 hr post fatigue and post massage ( $\bullet 2.51 \pm 0.91$ ) to 72 hr post ( $\bullet 1.91 \pm 0.97$ ) and 48 hr post ( $\bullet 2.34 \pm 1.01$ ) to 72 hr post ( $\bullet 1.91 \pm 0.97$ ). Significant differences ( $P \leq 0.05$ ) were found at time points post fatigue and 24 hr post and pre massage for M-L when compared to baseline. No significant differences were found at time points 24 hr post fatigue and post massage, 48 hr post and 72 hr post when compared to baseline. Significant differences were found between time points; post fatigue ( $\bullet 1.65 \pm 0.88$ ) to 24 hr post and pre massage ( $\bullet 2.59 \pm 1.73$ ), 24 hr post fatigue and pre massage ( $\bullet 2.59 \pm 1.73$ ) to 24 hr post and post massage ( $\bullet 1.93 \pm 1.35$ ), 24 hr post and pre massage ( $\bullet 2.59 \pm 1.73$ ) to 48 hr post ( $\bullet 1.86 \pm 1.12$ ), 24 hr post and pre massage ( $\bullet 2.59 \pm 1.73$ ) to 72 hr post ( $\bullet 1.21 \pm 0.49$ ), 24 hr post fatigue and post massage ( $\bullet 1.93 \pm 1.35$ ) to 72 hr post ( $\bullet 1.21 \pm 0.49$ ) and 48 hr post ( $\bullet 1.86 \pm 1.12$ ) to 72 hr post ( $\bullet 1.21 \pm 0.49$ ).

Displayed below is the quadratic regression analysis (Figure 6.4(b)) completed for dynamic stability scores ( $n = 14$ ). The curves presented represent OSI, A-P and M-L stability.

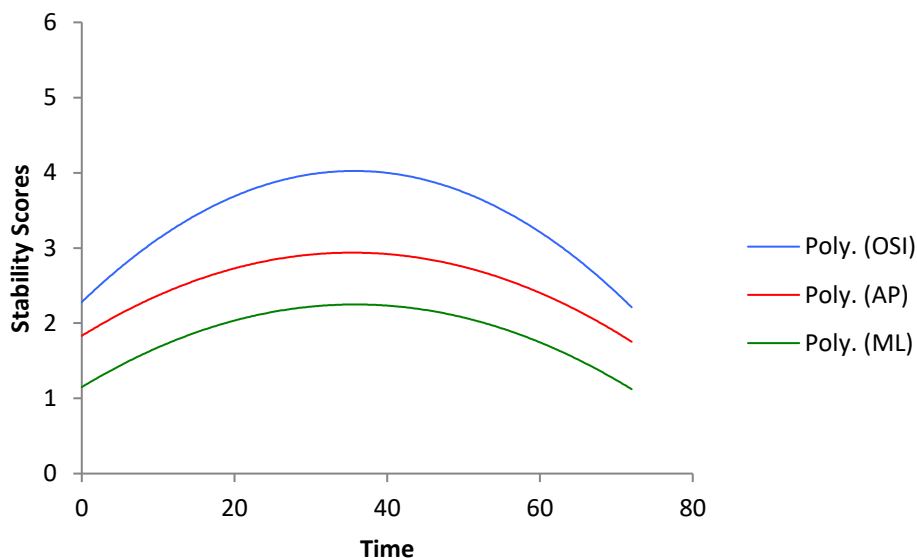


Figure 6.4(b): Quadratic Regression of Dynamic Stability Measures (OSI, A-P, M-L) Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with an Intervention of Soft Tissue Massage

The quadratic regression indicates that dynamic stability scores (OSI, A-P, M-L) bottom between 23 and 33 hr (OSI = 27.22 hr, A-P = 23.69 hr, M-L = 32.48 hr) and continuation of the

curve indicates that they would only return to baseline levels between 47 and 65 hr (OSI = 54.44 hr, A-P = 47.37 hr, M-L = 64.95 hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 6.3.

<b>Stability Plane</b>	<b>Quadratic Regression Equation</b>	<b><math>r^2</math> Value</b>	<b>Minima in hr</b>	<b>Maxima in hr</b>
OSI	$y = -0.0014x^2 + 0.0978x + 2.2805$	0.65	27.22	54.44
A-P	$y = -0.0009x^2 + 0.0625x + 1.832$	0.57	23.69	47.37
M-L	$y = -0.0009x^2 + 0.0615x + 1.1495$	0.78	32.48	64.95

Table 6.3: Displaying the  $r^2$  values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves Dynamic Stability Scores of OSI, A-P and M-L

It can be seen from the  $r^2$  values displayed in table 6.3 that there is a not a strong correlation presented for all variables tested (OSI,  $r^2 = 0.65$ , A-P,  $r^2 = 0.57$  and M-L,  $r^2 = 0.78$ ). Thus, indicating that the minima and maxima hours presented in the predictive curve for all variables are good.

• = where significant differences were found between mean scores.

#### **6.4 Discussion:**

The aim of the present study was to investigate the temporal pattern of knee flexor eccentric strength at speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$ ,  $300^\circ \cdot s^{-1}$  and dynamic stability (OSI, A-P and M-L) post soccer specific fatigue with an intervention of soft tissue massage at 24 hours post fatigue. Research in the area of soft tissue massage as a recovery tool is contradictory and this mainly is attributed to optimal time of use (Cafarelli 1990; Tidus et al., 1995; Shoemaker et al., 1997; Ernst., 1998; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014), effectiveness of technique (Petrofsky et al., 2008; Tew

et al., 2010; Mori et al., 2014; Caldwell et al., 2016) and experience of the clinician administering (Goats., 1994; Tidus et al., 1995; Shoemaker et al., 1997; Tidus., 1999; Hemmings., 2001; Ogai et al., 2008).

The principles of sports massage are to remove fatiguing by products as a result of fatigue and decrease DOMS (Mosaka, 2005; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). Fatigue post (Greig., 2008; Small et al., 2009) event and DOMS (Clarkson et al., 1992; Cheung et al., 2003) have both been shown to decrease muscle function and particularly eccentric strength. Findings from the studies of Clarkson et al., (1992); Cheung et al., (2003) have emphasised the negative effects localised (Chapter 4) and soccer specific fatigue (Chapter 5) have on the function of the hamstring muscle group. This is in relation to eccentric strength and dynamic stability and how this extends through the 72 hr temporal pattern post fatigue. The present study analysed the temporal pattern of these functions post soccer specific fatigue when soft tissue therapy was applied 24 hr post.

#### ***6.4.1 Eccentric Strength:***

Results displayed in 7.3.1 show that the acute effects of fatigue are consistent with previous research (Greig., 2008; Small et al., 2009; Small 2010) and results contained within chapters 4 and 5. Initial responses to fatigue show a reduction of up to 16% and this extends in to the temporal pattern post fatigue where decrease continues to 24 hr post fatigue, upto 26%. These findings within chapter 5 provided the foundations for justification of where to apply the intervention of massage to analyse the effect this had on the temporal pattern. The present study applied an intervention of soft tissue massage at 24 hours post fatigue to determine the effect this had on the temporal pattern. Chapter 5 highlighted that the minima of the predicted curves from the quadratic regression ranged from 35.84 – 40.65 for all variables of eccentric strength ( $r^2$  range: 0.86 – 0.97). This provided justification for applying the massage at 24 hr to try to accelerate this period of recovery. The predictive curves in chapters 4 and 5 were key to informing where to implement the intervention strategy. It can be seen that the massage has catalysed a positive response with regards the temporal pattern. Mean scores for AvgPkt<sub>eccH</sub> and Pkt<sub>eccH</sub> increase post the intervention of massage and this is supported with the post analysis of variance data that showed significant increases between time points in these values. Mean scores indicating an improvement of up to 10% in AvgPkt<sub>eccH</sub> and Pkt<sub>eccH</sub> and highlighting the effectiveness of utilising polynomial regression to guide the timing of

intervention strategies in recovery. The significant differences between time points were predominantly noticed between 24 hr post fatigue and pre massage and 48/72 hr post fatigue. It is also noted that no significant differences within  $^{\circ}\text{PKT}_{\text{eccH}}$  were observed for any of the time points within the temporal pattern post fatigue. When analysing the mean scores produced it highlighted that there were increases in angle from baseline measures to 24 hr post and then after this 24 hr time point the angle began to gradually decrease, which contradicts findings in chapter 4 and 5 and supports the effectiveness of massage as a recovery technique if implemented within an appropriate time frame.

Assumptions drawn from this and comparing these findings to those displayed in chapter 5 indicate that the massage has accelerated the recovery process within the muscles (Rinder et al., 1995; Gupta et al., 1996; Farr et al., 2002; Robertson et al., 2004; Moraska., 2007) and potentially had a positive effect on DOMS (Moraska., 2005). This supports the notion that the massage delivered has increased blood flow to the area, encouraged lymphatic drainage and this has promoted the removal of the fatiguing bi-products that have built up within the tissue during game play (Ernst 1998; Zainuddin et al., 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). Research listed associated with these benefits of massage have exhibited contrasting findings (Cafarelli 1990; Tidus et al., 1995; Shoemaker et al., 1997; Ernst., 1998; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014) and these differences have highlighted key considerations which include experience of the clinician, length of time massage is delivered for, technique, depth and what time point it should be implemented (Nedelec et al., 2013). Within the present study positive effects have been shown on the measures of eccentric strength. As stated consistently within recent research, injury prevention strategies require a multi factorial approach (Arnason et al., 2008; Myer et al., 2012; Opar et al., 2012; Alentorn-Geli et al., 2015; Ekstrand et al., 2016) and although massage positively affects the temporal pattern of eccentric strength, the effects on dynamic stability must be ascertained to establish an overall effect.

### **6.4.2 Dynamic Stability:**

On analysis of the dynamic stability scores, the acute effects of the soccer specific fatigue were consistent with the previous study (chapter 5) and research indicating that there is a reduction in dynamic stability post fatigue (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). The previous two studies expanded current literature by analysing the temporal pattern post fatigue and both highlighted the deficits were most prominent in A-P stability. Chapter 5 highlighted that the minima of the predicted curves from the quadratic regression ranged from 35.77 – 37.03 for all variables of eccentric strength ( $r^2$  range: 0.86 – 0.89). This provided justification for applying the massage at 24 hr to try to accelerate this period of recovery. The mean scores presented in figure 4.4, again highlight that M-L scores of all players were better than those of A-P stability and this was consistent through each time point. This could potentially highlight the differences between the afferent-efferent pathways associated with maintaining M-L and A-P stability (Zimny.,1988; Hogervorst et al., 1998); thus, potentially highlighting potential pre cursors for ACL and hamstring injury.

It was evident from the results presented that an intervention of soft tissue therapy at 24 hr post fatigue had a positive effect of the temporal pattern of recovery for all stability measures, as when compared to baseline scores they had all recovered at 72 hr post fatigue. This was reiterated by the quadratic regression analysis as it highlighted that the dynamic stability scores (OSI, A-P, M-L) presented a minima curve near to or shortly post massage and were all fully recovered by 65 hr, which is comparable to the 74 hr in chapter 5. Again, differences were exhibited between M-L and A-P measures. It was identified that when compared to baseline M-L only showed significance up to 24 hr post fatigue and pre massage and no significance was found with the remaining time points. A-P stability demonstrated significant differences up to 24 hr post fatigue and post massage. This again emphasises the differences between A-P and M-L stability and indicates that there is a clear EMD through either the effected response or the afferent signal generated by the mechanoreceptors within the joint or tissue. This neuromuscular delay could ultimately result in the joint (ACL) or the muscle (hamstring) being at greater risk of injury (Hewett et al., 1999; Laurin et al., 2011; Myer et al., 2012; Herman et al., 2012; Chen et al., 2013; Alentorn-Geli et al., 2015; Harput et al., 2015; Croix et al., 2015). It is important to note that significant differences were exhibited within time points and these



were most notable at 24 hr post fatigue and pre massage and 48 hr post fatigue for all dynamic stability measures (OSI, A-P and M-L). These differences highlighted significant improvements post massage and highlight the positive effect the massage had on recovery and accelerating the recovery at this pre-determined stagnant period between 24 and 48 hr post fatigue (Ernst 1998; Zainuddin et al., 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Nedelec et al., 2013; Portilo-Soto et al., 2014)

### **6.4.3 Synopsis:**

Effectiveness of soft tissue therapy as a recovery tool post event has been refuted through research and contradictory evidence identified (Cafarelli 1990; Tidus et al., 1995; Shoemaker et al., 1997; Ernst., 1998; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). It is acknowledged that the evidence examining the effectiveness of its use and the inconsistencies within conclusions have been associated with skills of the therapist, depth of techniques applied, time administered for and when administered (Petrofsky et al., 2008; Tew et al., 2010; Wiltshire et al., 2010; Nedelec et al., 2013; Mori et al., 2014; Caldwell et al., 2016). The present study factored in these considerations within the design and addressed each by utilising an experienced clinician in excess of 10 years' soft tissue therapy in elite sport, not spending in excess of ten minutes on one isolated area (Mosaka., 2005; Changela et al., 2012; Shin et al., 2015) and most notably using the temporal pattern post fatigue to guide where to apply the intervention to accelerate recovery. This period was identified within chapter 5 through the polynomial regression analysis as being the 24 – 48-hr period and to accelerate this period soft tissue therapy was applied at 24 hr post soccer specific fatigue. Comparing findings from chapter 5 to the current chapter highlights the improvements within the temporal pattern of recovery when analysing mean scores and significance values for all eccentric strength and dynamic stability variables, indicating that the intervention of massage has had a positive effect. It also shows through the predictive curve that dynamic stability was recovered at 65 hr and functional strength at 70 hr showing a decrease in recovery time compared to previous chapters. Although, it is acknowledged that each study was completed on a different cohort of players; players were recruited from the same level of professional football and were subjected to similar training protocols and weekly demands.

Fatigue and its effect on eccentric strength and dynamic stability are the key aetiological factors that have been most strongly associated with ACL and hamstring injury (Lattinzo et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Riberio et al., 2010; Thomas et al., 2010; Gear 2011; Changela et al., 2012). Fatigue is classed as an unalterable factor as players are subjected to every time they train or take part in game play, so minimising the effects of fatigue or developing player's resistance to fatigue has to be a key focus within injury prevention (Van Mechelen et al., 1992). Links between dynamic stability, particularly A-P, and the hamstrings are clear and as a result of fatigue deficits occur in both. These deficits are clearly linked just through the basis of simple anatomy. The semitendinosus and semimembranosus muscle within the hamstring group have a key role in stabilising the ACL and functionally when performing must exhibit good eccentric control to meet the demands placed through them. Differing theories have been presented to why these structures are more susceptible to injury through performance and stabilisation of the joint within game play is heavily reliant on eccentric strength to control movements, but also an efficient and effective neuromuscular pathway (Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Greig, 2008; Adachi et al., 2009; Greig et al., 2009; Small et al., 2009).

Fatigue has been identified to affect the intrafusal fibres within tissues and the effectiveness of the mechanoreceptors within muscle and joint, which would ultimately result in EMD (Ristanis., 2009; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). This could create an overstretch within muscle tissue or excess range/force being exerted through a joint, factors associated with ACL and hamstring injury. The present study has highlighted that massage can decrease the effects of fatigue by removal of bi products associated with fatigue, which is facilitated by accelerating the lymphatic drainage and blood flow (Ernst 1998; Zainuddin et al., 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). The findings from the present study can provide clinicians and medical teams within clubs with information regarding the temporal pattern and potential use of sports massage as a recovery tool. It will also act as guidance on when to implement other recovery interventions. Another method to combat the effects of fatigue is to look at methods of reducing the effects of fatigue within game play, which could potentially be brought about by a rule change similar to ones completed in other sports.

## **6.5 Conclusion:**

Soft tissue therapy implemented at 24 hr post fatigue had significant positive effects on  $\text{AvgPkt}_{\text{eccH}}$  and  $\text{Pkt}_{\text{eccH}}$ , dynamic stability measures of OSI, A-P and M-L post soccer specific fatigue. This was identified by comparisons to the findings in chapter 5 and although it is acknowledged that these were different groups of players, these players were from the same level of football and had similar training, game and weekly demands. Differences were observed between the recovery patterns of A-P and M-L stability measures, with M-L stability showing quicker speeds of recovery within the temporal pattern. It was also noted that there were no significant changes identified within angle of peak torque measures throughout any time point within the study. Mean scores observed demonstrated that the acute effects of fatigue created increases in angle, which peaked at 24 hr post fatigue and pre massage. The significance of these findings indicate the importance of time of implementation of soft tissue therapy. They also demonstrate that soft tissue therapy is an appropriate recovery tool, if completed by a clinician with an appropriate skill set. The improvement in eccentric strength and dynamic stability measures as a result of soft tissue therapy post fatigue highlight that this could be an effective strategy to employ as a recovery tool, but also as a preventative strategy for reducing the chance of sustaining a hamstring or ACL injury. Players maybe more susceptible to these types of injury in periods of fixture congestion if the biomechanical measures of eccentric strength and dynamic stability have not fully recovered within the 72 hr window post-game.

## **Chapter 7: The Efficacy of Interchange on the Temporal Recovery of Eccentric Hamstrings Strength and Dynamic Stability**

### **7.1 Introduction:**

It is commonplace within sport for governing bodies to implement rule changes to affect the incidence of injuries. Generally, over the past two decades rule changes implemented by FIFA, the world governing body, have focussed their attentions on reducing contact injuries. Such rules implemented have included prohibiting tackling from behind, although there is limited evidence to determine if these types of intervention have achieved their goal. A measure introduced indirectly to combat the issue of fatigue and to potentially reduce the impact of non-contact musculoskeletal injuries was the increase in substitutions from two to three and the increase of available substitutes on the bench. This provided the option to the coaching staff to cover most positions on the pitch and theoretically this would allow players condition to be monitored and ultimately result in a substitution when players displayed signs of fatigue.

An intervention implemented in sports such as rugby league and AFL (Australian Football League) is the introduction of the interchange (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Sirotic et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013; Waldron et al., 2013; Black et al., 2013). This allows players to be substituted and brought back in to the game at a different stage, with only a limitation on the number of interchanges allowed rather than not allowing the same player back on the field of play. Interchanges accompanied with modern technology like GPS and judgements made from medical and coaching staff, allows players to be monitored closely. If there is an indication of fatigue or a drop in performance that could potentially be associated with a player becoming tired then more often than not they are removed from the field of play and replaced, so they can rest and recover. Epidemiological and aetiological evidence does suggest that this ruling has resulted in a decrease in non-contact musculoskeletal injury (Gabbett., 2005; Orchard et al., 2011).

Orchard et al., (2011) concluded that the use of interchanges decreased the incidence of hamstring injuries within squads throughout the ARF. They analysed 56,320 players over a 7-year playing period and utilised a general estimating equation based on previous seasons injury data. It could be seen that as a result of squads making an increased number of interchanges,

increasing from 27 interchanges across squads in 2003 to 117 interchanges in 2010 hamstring injuries were cut from 899 a season to 416. It could be argued that modern interventions such as specific training techniques or development of preventative strategies at the club contributed to this, as they would have been developed in a 7-year period. Making comparisons across to football where there is no interchange rule, it can be seen that regardless of the implementation of common preventative strategies like eccentric strengthening (Askling et al., 2003; Arnason et al., 2008; Mackey et al., 2011; Petersen et al., 2011) or specific warm up protocols (FIFA 11+ and Harmoknee, Daneshjoo et al., 2012) the incidence of hamstring injuries have not decreased (Woods et al., 2004; Arnason et al., 2008; Engebretsen et al., 2010; Ekstrand et al., 2011; Opar et al., 2012). Interestingly within this paper they indicated that there had also been a reduction of knee injuries. It seems logical to assume that due to a reduction in fatigue of the hamstrings biomechanical markers such as eccentric strength and dynamic stability remain high and this results in the hamstrings maintaining its role as a stabiliser of the knee. However, it cannot be assumed that this is the case across sports due to the different demands of games, but it does provide enough evidence to indicate that further investigation of this is warranted in football. It is also important to note that their research highlighted that a high number of interchanges resulted in an increased number of injuries being sustained for the opposition. This demonstrates the importance of the interchange and frequent use of it within game play, but also highlights that as a result of an interchange the demands become greater on the opposition.

Evidence is conclusive that biomechanical and physiological fatigue occurs in the later stages of each half and it is within these stages of the game that players are at the greatest risk of sustaining a non-contact musculoskeletal injury (Mohr et al., 2004; Greig et al., 2008; Greig et al., 2009; Small et al., 2009). It has been indicated that soccer players experience temporary fatigue during game play and it is this temporary fatigue that is linked to players sustaining injury (Koller et al., 2006; Greig et al., 2008; Greig et al., 2009; Small et al., 2009; Ekstrand et al., 2011; Opar et al., 2012). During game play players will move between energy systems throughout the game, utilising the aerobic energy system to recover after periods of high intensity. It is these periods of high intensity within a game that are subsequently followed by a reduction in sprint performance in players. This indicates that when high intensity is experienced a reduction in muscular function occurs, which could be linked to biomechanical pre-cursors of injury, like eccentric strength and dynamic stability (Mohr et al., 2003). Physiologically these periods of intense play and reductions in performance have been correlated with increases in blood lactate and glycogen depletion (Mohr et al., 2003). It has

been theorised that reductions in dynamic stability and neuromuscular response have been attributed with blood lactate desensitizing muscle receptors (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). The combination of glycogen depletion, which can disrupt the excitation coupling required for contraction (Stephenson et al., 1999), and the build-up of lactate in the muscle tissue could result in decreased eccentric strength and dynamic stability. The reduction in these functions would expose the athlete to an increased chance of injury. Potentially suggesting that if these fatiguing factors could be controlled and players were given periods of recovery post these periods of high intensity play then their chance of sustaining injury would be decreased.

Given the evidence surrounding the use of interchange in other sports and the lack of research in this area in football, the present study is designed to examine the effects of interchange on the temporal pattern of eccentric strength and dynamic stability post soccer specific fatigue. A modification of the SAFT<sup>90</sup> protocol will be implemented to induce the soccer specific fatigue with interchange. The interchanges will be dispersed through the 90-minute protocol allowing the players to have periods of rest throughout the 90 minutes. If it is identified that decreases of eccentric strength and/or dynamic stability are reduced, then this could provide justification for implementation of interchanges within football. Eccentric strength and dynamic stability within research are traditionally utilised as markers of fatigue or pre cursors of injury, as highlighted in the literature discussed. It is evident within injury audits that fatigue is a major contributory factor with most non-contact musculoskeletal injuries occurring in the later stages of each half. Therefore, if implementing interchange reduces these effects then this could potentially have a positive effect on hamstring and ACL injury occurrence and thus guide potential rule changes within the game. It is also important to note that interchange throughout sports such as rugby league and ARF are utilised for tactical gain and the positive contribution to non-contact musculoskeletal injury is also accompanied by the opportunity to intervene in game play and effect patterns of game immediately.

## **7.2 Methodology:**

### **7.2.1 Participants:**

Sixteen male professional soccer players completed the present study, with a mean age and SD of  $22.64 \pm 4.70$  years, height  $185.41 \pm 4.72$ cm and body mass of  $77.62 \pm 6.08$  kg. All participants were screened to ensure suitability for the study in relation to inclusion/exclusion criteria (3.2.2) and provided written informed consent in accordance with the department and university ethical procedures as listed in the general methodology (3.2.1).

### **7.2.2 Experimental Design:**

Before completion of the familiarisation and testing protocols, all players in the study were subjected to the appropriate anthropometric measures outlined in the general methodology (3.3). On completion of the relevant checks and consent being obtained players were then asked to complete a warm up, which consisted of 10 minutes of the SAFT<sup>90</sup> protocol (3.3.3(b)). Post completion of the warm up participants were supervised through a series of dynamic stretches, which included the hamstrings, quadriceps, adductors, abductors and gastrocnemius. The stretches were completed for 12 repetitions within a 30-second period and this was consistent for all participants (Herda et al., 2008; Page, 2012). Static stretching was not considered as it has been shown to have a negative effect on dynamometer-measured strength (Herda et al., 2008; Siatras et al., 2008; Sekir et al., 2010; Page, 2012). This was carried out before completion of any familiarisation or testing protocols. Familiarisation trials were then completed for the soccer specific fatigue protocol, IKD testing and BSS testing (3.3.3(b), 3.3.1 and 3.3.2).

Post the familiarisation trials testing could proceed. Players were invited back to the laboratory 7 days' post familiarisation testing and completed measures on the IKD and BSS, the testing protocols for each are detailed in the general methodology (3.3.1 and 3.3.2). Post obtaining baseline scores the players were then subjected to the soccer specific fatigue protocol (3.3.3(b)), which was redesigned to include periods of interchange (figure 9). During completion of the fatigue protocol Borg's (1970) 6-20 point scale was used to record the participant's subjective rating of perceived exertion and was recorded at rest and post each 15 minute period of the SAFT<sup>90</sup>. In addition to this heart rate (HR) was also recorded every 15 repetitions during each

trial of each fatigue protocol using a HR monitor (Polar, Team system, Finland). Attendance time was noted for each player with regards baseline measures and the soccer specific fatigue protocol and for the subsequent time points to monitor the temporal pattern post fatigue, they were asked to return at exactly the same time (Drust et al., 2005). To monitor the temporal pattern of recovery of the athlete and the effect interchange has on this period, IKD and BSS measurements were taken immediately post fatigue, 24 hr, 48 hr and 72 hr post fatigue, again all measurements were consistent with testing procedures detailed in the general methodology (3.3.1 and 3.3.2). The data analysis applied to the soccer specific fatigue protocol with the intervention of interchange was consistent with chapter 3.4 of the General Methodology.

**7.2.3 Interchange Protocol:**

Periods of interchange were introduced into the SAFT<sup>90</sup> protocol (3.3.3(b)) at 15 min intervals. The SAFT<sup>90</sup> protocol consists of 3x15 min repeated intervals representing the first half, followed by a 15 minute interval representing half time and finishing with a further 3x15 minute repeated intervals representing the second half (3.3.3(b)). The first and second half periods of the SAFT<sup>90</sup> protocol replicated demands and movements encountered by players within game play and these were replicated throughout both of these periods. At half time players completed no activity, to replicate the half time period within a game. To apply periods of interchange within the SAFT<sup>90</sup> protocol the second intervals within the first and second half were removed (figure 7). This subjected the players to a period of running for 15 minute, which was subsequently followed by a period of rest (interchange), within each half.

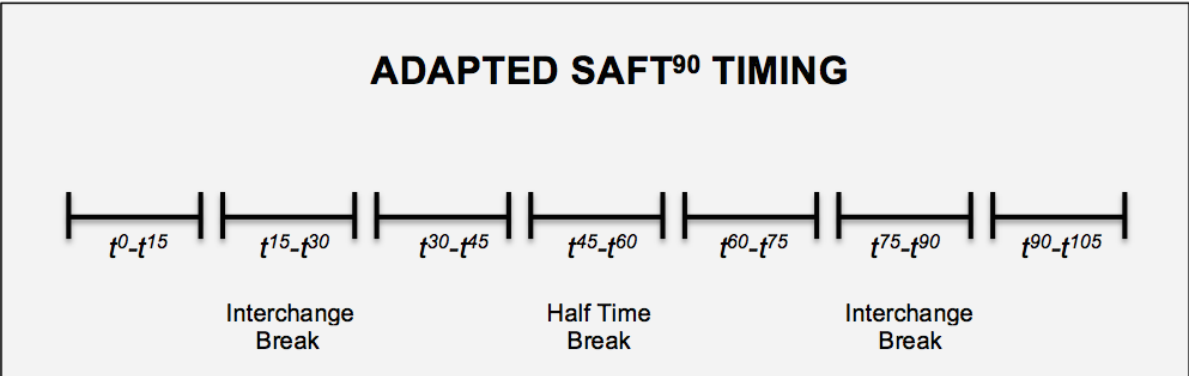


Figure 7: Redesign of the SAFT<sup>90</sup> Protocol to Include Interchanges



### 7.2.4 Statistical Analysis:

$PkT_{eccH}$ ,  $AvgPkT_{eccH}$  and  ${}^{\circ}PkT_{eccH}$  for all 3 testing speeds and dynamic stability outcome measures of OSI, A-P and M-L were determined at baseline, post localised fatigue and at consistent time points at 24, 48 and 72 hr. Tests for outliers, to identify if the data was normally distributed and sphericity, for equal variance in the data, were then completed, as detailed in chapter 3.5 of the general methodology. The data was then analysed using a one way repeated measures analysis of variance (ANOVA) for each output measure to establish whether there were significant differences between the base line values and the testing periods post fatigue, 24 hr, 48 hr and 72 hr post fatigue, determining if there was a significant main effect for recovery time. All statistical analysis was performed using PASW Statistics Editor 18.0 for windows (SPSS Inc, Chicago, USA) with an accepted significance level set at  $P \leq 0.05$  (3.5). Quadratic regression analysis was completed as described in the general methodology (3.5).

## 7.3 Results:

### 7.3.1 Eccentric Strength:

Below are the results displaying the effects of soccer specific fatigue on the hamstring muscle group of player's ( $n = 16$ ) dominant leg  $AvgPkT_{eccH}60^{\circ} \cdot s^{-1}$ ,  $AvgPkT_{eccH}150^{\circ} \cdot s^{-1}$ ,  $AvgPkT_{eccH}300^{\circ} \cdot s^{-1}$  (figure 7.1(a)).

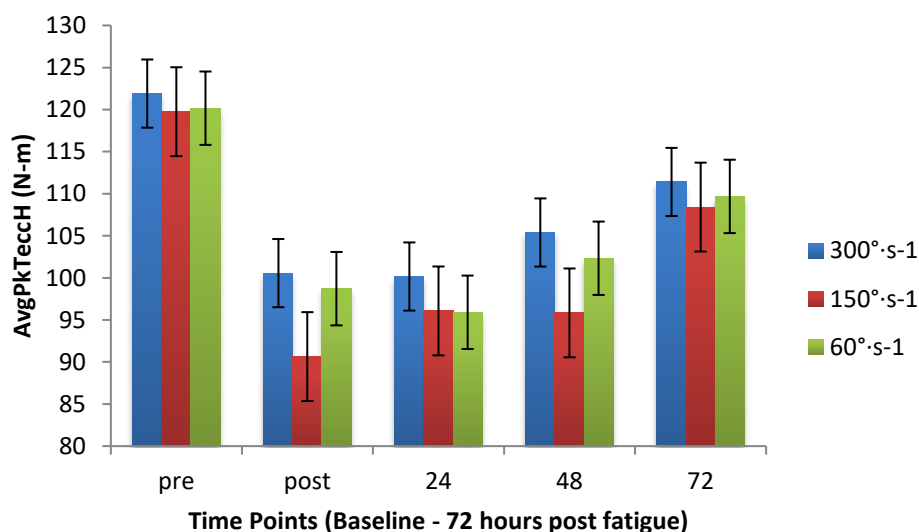


Figure 7.1(a): Temporal Pattern of Mean AvgPkT<sub>eccH</sub> Values over a 72 hr Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with Periods of Interchange at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup> with Standard Error ( $\pm$  SE)

At the slowest test speed (60°·s<sup>-1</sup>) for AvgPkT<sub>eccH</sub> analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline, except at 72 hr post, where no significant effect was found ( $P \geq 0.05$ ). Analysing means between time points also indicated significant differences, these were found at; post fatigue (98.71 $\pm$ 15.69N·m) to 72 hr post (109.68 $\pm$ 20.61N·m), 24 hr post fatigue (95.91 $\pm$ 16.94N·m) to 72 hr post (109.68 $\pm$ 20.61N·m), 48 hr post fatigue (102.33 $\pm$ 19.50N·m) to 72 hr post (109.68 $\pm$ 20.61N·m). Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of 150°·s<sup>-1</sup> with mean trend scores for baseline of 119.75 $\pm$ 25.78N·m and 72 hr post = 108.41 $\pm$ 21.20N·m. Analysing mean trends between time points also highlighted some significant differences ( $P \leq 0.05$ ). These were identified at; post fatigue (90.64 $\pm$ 16.08N·m) to 72 hr post (108.41 $\pm$ 21.20N·m), 24 hr post fatigue (96.07 $\pm$ 18.72N·m) to 72 hr (108.41 $\pm$ 21.20N·m), 48 hr post fatigue (95.83 $\pm$ 19.11N·m) to 72 hr post (108.41 $\pm$ 21.20N·m). Similar results at the final fast testing speed of 300°·s<sup>-1</sup> significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline, except at 72 hr where no significant differences were found ( $P \geq 0.05$ ). Analysing mean trends between time points also highlighted some significant differences ( $P \leq 0.05$ ). These were identified at 24 hr post fatigue (100.16 $\pm$ 17.38N·m) to 72 hr post (111.40 $\pm$ 20.42N·m) and 48 hr post fatigue (105.39 $\pm$ 17.98N·m) to 72 hr post (111.40 $\pm$ 20.42N·m).

Displayed below is the quadratic regression analysis (Figure 7.1(b)) completed for AvgPkJ<sub>eccH</sub> (n = 16). The curves presented represent AvgPkJ<sub>eccH</sub>60°·s<sup>-1</sup>, AvgPkJ<sub>eccH</sub>150°·s<sup>-1</sup>, AvgPkJ<sub>eccH</sub>300°·s<sup>-1</sup>.

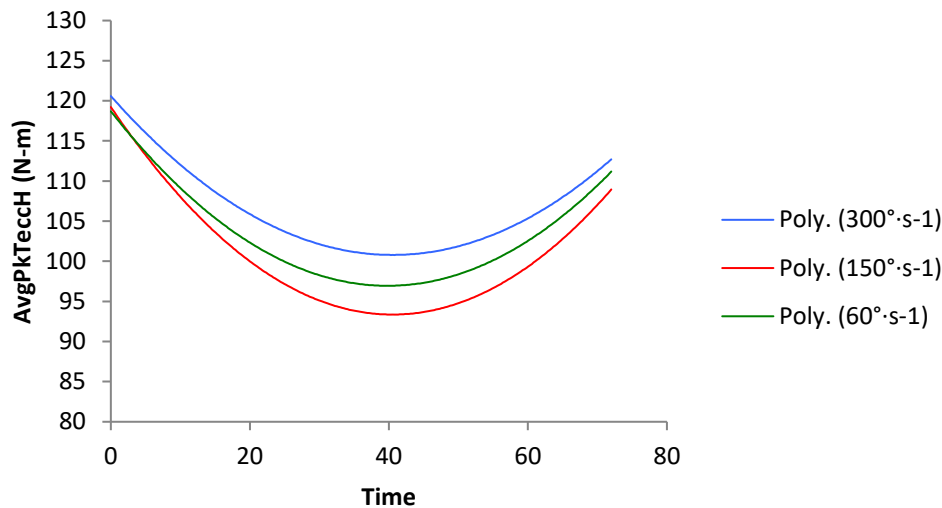


Figure 7.1(b): Quadratic Regression of AvgPkJeccH Post Soccer Specific Fatigue with Periods of Interchange at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup>

The polynomial regression indicates that AvgPkJ<sub>eccH</sub> values bottom between 35 and 42 hr (300°·s<sup>-1</sup> = 36.19 hr, 150°·s<sup>-1</sup> = 41.07 hr, 60°·s<sup>-1</sup> = 36.00 hr) and continuation of the curve indicates that they would only return to baseline levels between 72 and 83 hr (300°·s<sup>-1</sup> = 72.39 hr, 150°·s<sup>-1</sup> = 82.13 hr, 60°·s<sup>-1</sup> = 72.00 hr). The quadratic regression equation, r<sup>2</sup> values and the minima and maxima hours of the curve can be seen below in Table 7.1.

Isokinetic Speed	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
300°·s <sup>-1</sup>	y = 0.012x <sup>2</sup> - 0.9767x + 120.59	0.87	36.19	72.39
150°·s <sup>-1</sup>	y = 0.0157x <sup>2</sup> - 1.2758x + 119.22	0.99	41.07	82.13
60°·s <sup>-1</sup>	y = 0.0137x <sup>2</sup> - 1.092x + 118.68	0.86	36.00	72.00

Table 7.1: Displaying the  $r^2$  values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves AvgPkJ<sub>eccH</sub> at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$  and  $300^\circ \cdot s^{-1}$

It can be seen from the  $r^2$  values displayed in table 7.1 that there is a good correlation presented for variables tested AvgPkJ<sub>eccH</sub> $60^\circ \cdot s^{-1}$ ,  $r^2 = 0.86$  and AvgPkJ<sub>eccH</sub> $300^\circ \cdot s^{-1}$ ,  $r^2 = 0.87$ ). Thus, indicating that the minima and maxima hours presented in the predictive curve are good. AvgPkJ<sub>eccH</sub> $150^\circ \cdot s^{-1}$ ,  $r^2 = 0.99$  indicating an excellent correlation between strength and time indicating the minima and maxima predictive curve is excellent.

Displayed below are the results displaying the effects of soccer specific fatigue on the hamstring muscle group of player's (n = 16) dominant leg PkJ<sub>eccH</sub> $60^\circ \cdot s^{-1}$ , PkJ<sub>eccH</sub> $150^\circ \cdot s^{-1}$ , PkJ<sub>eccH</sub> $300^\circ \cdot s^{-1}$  (figure 7.2(a)).

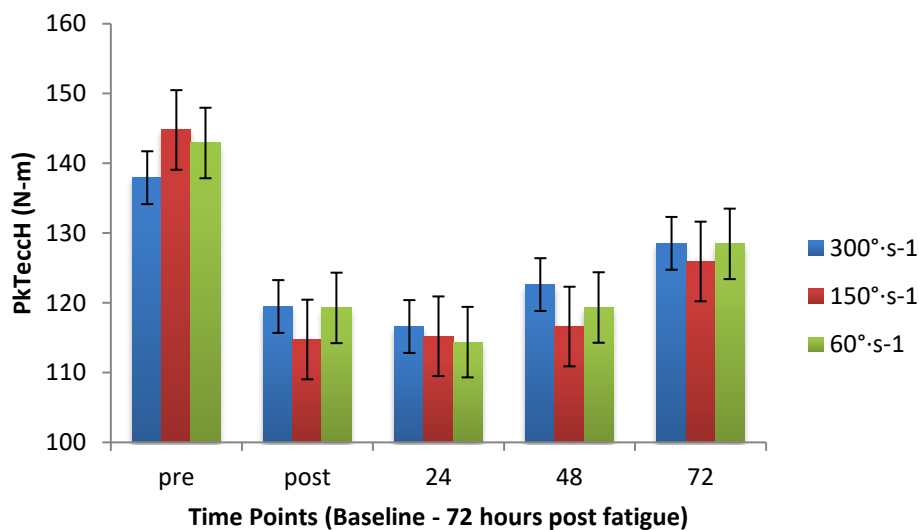


Figure 7.2(a): Temporal Pattern of Mean PkJ<sub>eccH</sub> Values over a 72 hr Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with Periods of Interchange at Isokinetic Speeds of  $60^\circ \cdot s^{-1}$ ,  $150^\circ \cdot s^{-1}$ ,  $300^\circ \cdot s^{-1}$  with Standard Error ( $\pm$  SE).

At the slowest test speed ( $60^\circ \cdot s^{-1}$ ) for PkJ<sub>eccH</sub> analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline. Analysing means between time points also indicated significant differences, these were found at; 24 hr post fatigue ( $114.37 \pm 18.06 N \cdot m$ ) to 72 hr post ( $128.45 \pm 25.65 N \cdot m$ ), 48 hr post fatigue

( $119.33 \pm 24.65 \text{ N}\cdot\text{m}$ ) to 72 hr post ( $128.45 \pm 25.65 \text{ N}\cdot\text{m}$ ). Significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline at the testing speed of  $150^\circ \cdot \text{s}^{-1}$  with mean trend scores for baseline of  $144.78 \pm 31.18 \text{ N}\cdot\text{m}$  and 72 hr post =  $125.93 \pm 26.42 \text{ N}\cdot\text{m}$ . Results at the final fast testing speed of  $300^\circ \cdot \text{s}^{-1}$  significant differences ( $P \leq 0.05$ ) were found at all-time points when compared to baseline, except at 72 hr where no significant differences were found ( $P \geq 0.05$ ). Analysing mean trends between time points also highlighted some significant differences ( $P \leq 0.05$ ). These were identified at 24 hr post fatigue ( $116.61 \pm 19.82 \text{ N}\cdot\text{m}$ ) to 72 hr post ( $128.53 \pm 19.83 \text{ N}\cdot\text{m}$ ) and 48 hr post fatigue ( $122.61 \pm 17.78 \text{ N}\cdot\text{m}$ ) to 72 hr post ( $128.53 \pm 19.83 \text{ N}\cdot\text{m}$ ).

Displayed below is the quadratic regression analysis (Figure 7.2(b)) completed for  $\text{PkJ}_{\text{eccH}}$  ( $n = 16$ ). The curves presented represent  $\text{PkJ}_{\text{eccH}60^\circ \cdot \text{s}^{-1}}$ ,  $\text{PkJ}_{\text{eccH}150^\circ \cdot \text{s}^{-1}}$ ,  $\text{PkJ}_{\text{eccH}300^\circ \cdot \text{s}^{-1}}$ .

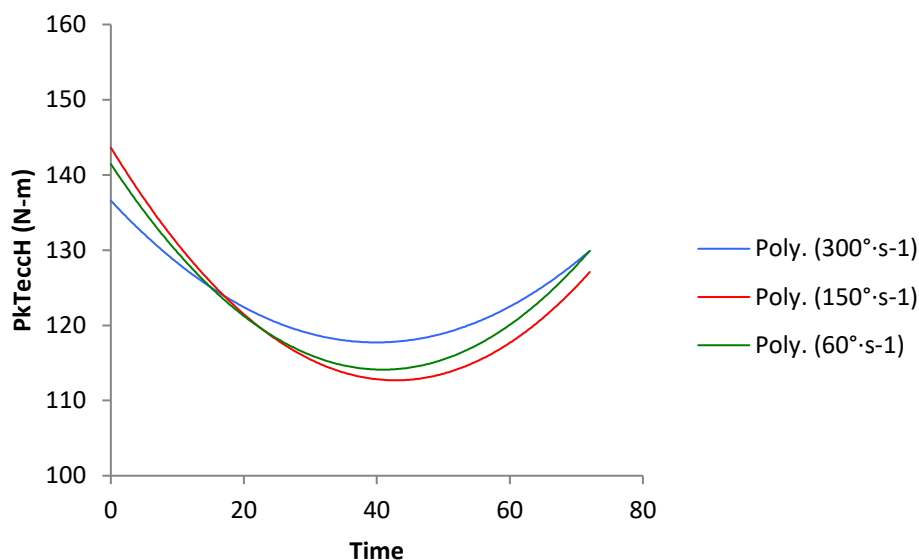


Figure 7.2(b): Quadratic Regression of  $\text{PkJ}_{\text{eccH}}$  Post Soccer Specific Fatigue with Periods of Interchange at Isokinetic Speeds of  $60^\circ \cdot \text{s}^{-1}$ ,  $150^\circ \cdot \text{s}^{-1}$  and  $300^\circ \cdot \text{s}^{-1}$

The quadratic regression indicates that  $\text{PkJ}_{\text{eccH}}$  values bottom between 35 and 40 hours ( $300^\circ \cdot \text{s}^{-1} = 35.34 \text{ hrs}$ ,  $150^\circ \cdot \text{s}^{-1} = 39.68 \text{ hr}$ ,  $60^\circ \cdot \text{s}^{-1} = 37.86 \text{ hrs}$ ) and continuation of the curve indicates that they would only return to baseline levels between 76 and 82 hr ( $300^\circ \cdot \text{s}^{-1} = 70.69 \text{ hr}$ ,  $150^\circ \cdot \text{s}^{-1} = 79.37 \text{ hr}$ ,  $60^\circ \cdot \text{s}^{-1} = 75.72 \text{ hr}$ ). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 7.2.

Isokinetic Speed	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
300°·s <sup>-1</sup>	y = 0.0118x <sup>2</sup> - 0.944x + 136.57	0.85	35.34	70.69
150°·s <sup>-1</sup>	y = 0.0169x <sup>2</sup> - 1.4452x + 143.63	0.95	39.68	79.37
60°·s <sup>-1</sup>	y = 0.0163x <sup>2</sup> - 1.3368x + 141.44	0.91	37.86	75.72

Table 7.2: Displaying the r<sup>2</sup> values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves PkT<sub>eccH</sub> at Isokinetic Speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup> and 300°·s<sup>-1</sup>

It can be seen from the r<sup>2</sup> values displayed in table 7.2 that there is a good correlation presented for variable PkT<sub>eccH</sub>300°·s<sup>-1</sup>, r<sup>2</sup> = 0.85). Thus, indicating that the minima and maxima hours presented in the predictive curve are good. PkT<sub>eccH</sub>60°·s<sup>-1</sup>, r<sup>2</sup> = 0.91 and PkT<sub>eccH</sub>150°·s<sup>-1</sup>, r<sup>2</sup> = 0.95 represent excellent correlations, indicating an excellent predictive curve highlighting minima and maxima values.

Displayed below are the results displaying the effects of soccer specific fatigue of the hamstring muscle group on player's (n = 16) dominant leg  $^{\circ}\text{Pkt}_{\text{eccH}} 60^{\circ}\cdot\text{s}^{-1}$ ,  $^{\circ}\text{Pkt}_{\text{eccH}}150^{\circ}\cdot\text{s}^{-1}$ ,  $^{\circ}\text{Pkt}_{\text{eccH}}300^{\circ}\cdot\text{s}^{-1}$  (figure 7.3).

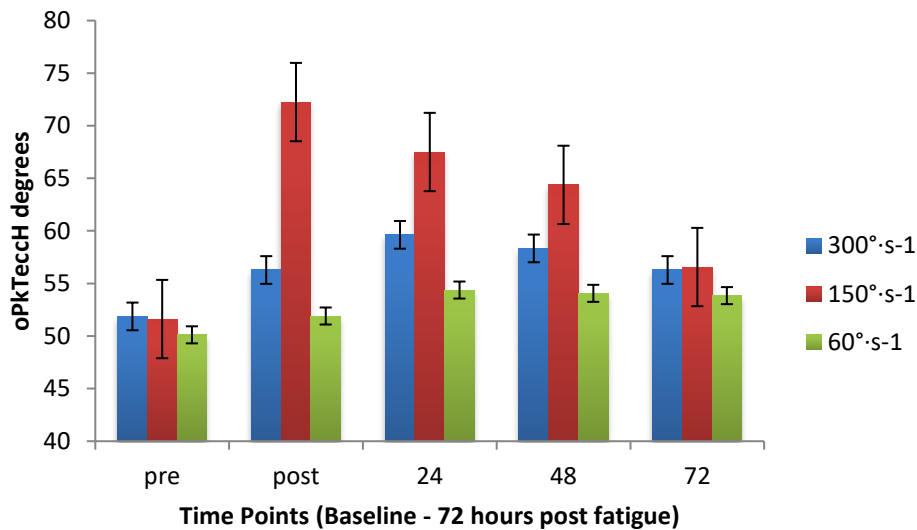


Figure 7.3: Temporal Pattern of Mean  $^{\circ}\text{Pkt}_{\text{eccH}}$  Values over a 72 hr Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with Periods of Interchange at Isokinetic Speeds of  $60^{\circ}\cdot\text{s}^{-1}$ ,  $150^{\circ}\cdot\text{s}^{-1}$ ,  $300^{\circ}\cdot\text{s}^{-1}$  with Standard Error ( $\pm$  SE)

Results from  $^{\circ}\text{Pkt}_{\text{eccH}}$  measures highlighted that when analysing means of all test speeds of  $60^{\circ}\cdot\text{s}^{-1}$ ,  $150^{\circ}\cdot\text{s}^{-1}$  and  $300^{\circ}\cdot\text{s}^{-1}$  analysis of variance showed that there were no significant differences ( $P \leq 0.05$ ) at any time points when compared to baseline or between time points. Polynomial regression analysis was not completed within  $^{\circ}\text{Pkt}_{\text{eccH}}$  due to the lack of significant effect fatigue had on change of angle.

### 7.3.2 Dynamic Stability:

Below are the results displaying the effects of localised fatigue of the hamstring muscle group on player's (n = 16) dominant leg OSI, A-P and M-L dynamic stability scores (figure 7.4(a)).

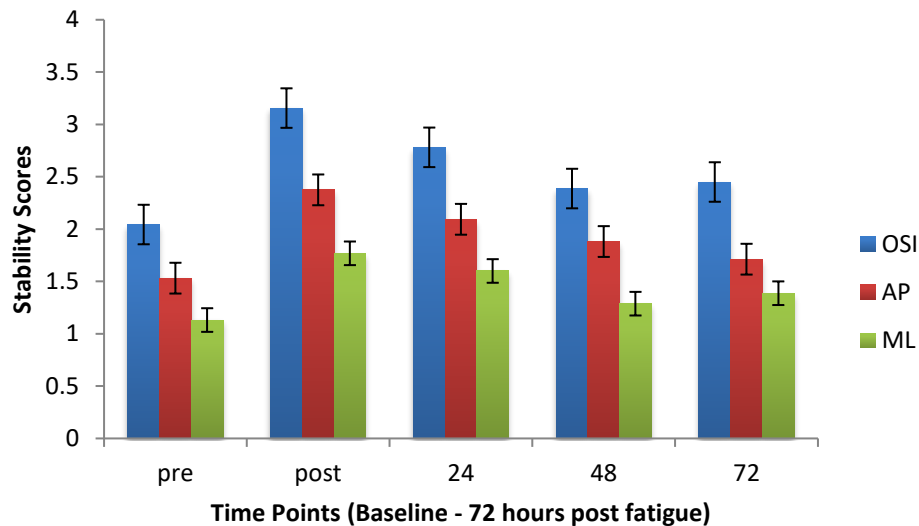


Figure 7.4(a): Temporal Pattern of Mean Dynamic Stability Values over (a 72-hour Period Post Soccer Specific Fatigue (SAFT<sup>90</sup>) with Periods of Interchange Referring to OSI, A-P and M-L with Standard Error ( $\pm$  SE)

The OSI post an analysis of variance showed that there were significant differences ( $P \leq 0.05$ ) at all-time points when compared to baseline. It was also identified that there were notable significant differences ( $P \leq 0.05$ ) within time points through the temporal pattern post fatigue, which were found between post fatigue ( $\bullet 3.16 \pm 1.34$ ) and to 48 hr post ( $\bullet 2.39 \pm 1.00$ ) ( $\bullet 4.84 \pm 2.31$ ) and 24 hr post fatigue ( $\bullet 2.78 \pm 1.10$ ) to 72 hr post ( $\bullet 2.45 \pm 1.10$ ). Analysis of variance for A-P presented significant findings ( $P \leq 0.05$ ) for all time periods when compared to baseline values, except between baseline and 72 hr post fatigue where no significant differences were found ( $P \leq 0.05$ ). Significant differences ( $P \leq 0.05$ ) were also found for the time periods post fatigue to 72 hr post fatigue ( $\bullet 2.38 \pm 1.05$  and  $\bullet 1.71 \pm 0.74$ ) and 24 hr post fatigue to 72 hr post fatigue ( $\bullet 2.09 \pm 0.86$  and  $\bullet 1.71 \pm 0.74$ ). Significant differences ( $P \leq 0.05$ ) were found at time points baseline to 24 hr post fatigue for M-L. No significance ( $P \geq 0.05$ ) was found at time point's 48 hr post and 72 hr post when compared to baseline. On analysis of mean scores between time points for M-L significant differences were found ( $P \leq 0.05$ ). The



time points were post fatigue ( $1.77 \pm 0.77$ ) to 48 hr post ( $1.29 \pm 0.53$ ) and post fatigue ( $1.77 \pm 0.77$ ) to 72 hr post ( $1.39 \pm 0.76$ ).

Displayed below is the quadratic regression analysis (Figure 7.4(b)) completed for dynamic stability scores ( $n = 16$ ). The curves presented represent OSI, A-P and M-L stability.

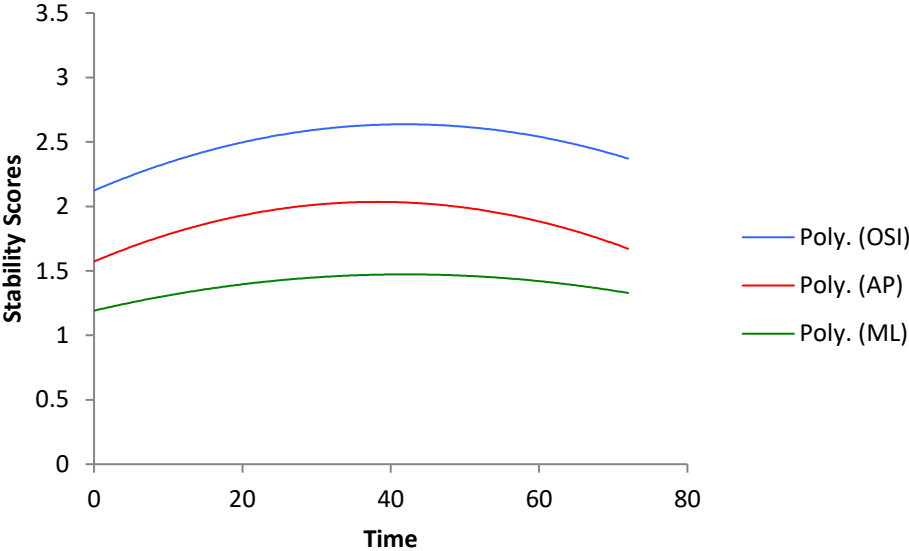


Figure 7.4(b): Quadratic Regression of Dynamic Stability Measures (OSI, A-P, M-L) Post Soccer Specific Fatigue with Periods of Interchange

The quadratic regression indicates that dynamic stability scores (OSI, A-P, M-L) bottom between 16 and 34 hr (OSI = 22.50 hr, A-P = 33.58 hr, M-L = 16.00 hr) and continuation of the curve indicates that they would only return to baseline levels between 32 and 68 hr (OSI = 45.00 hr, A-P = 67.16 hr, M-L = 31.99 hr). The quadratic regression equation,  $r^2$  values and the minima and maxima hours of the curve can be seen below in Table 7.3.

Stability Plane	Quadratic Regression Equation	r <sup>2</sup> Value	Minima in hr	Maxima in hr
OSI	$y = -0.0003x^2 + 0.0245x + 2.1231$	0.54	22.50	45.00
A-P	$y = -0.0003x^2 + 0.0242x + 1.5722$	0.81	33.58	67.16
M-L	$y = -0.0002x^2 + 0.0134x + 1.1909$	0.38	16.00	31.99

Table 7.3: Displaying the r<sup>2</sup> values, the Quadratic Regression Equation, Minima and Maxima for each of the Curves Dynamic Stability Scores of OSI, A-P and M-L

It can be seen from the r<sup>2</sup> values displayed in table 7.3 that there is a not a poor correlation presented for variables OSI, r<sup>2</sup> = 0.54, and M-L, r<sup>2</sup> = 0.38. Thus, indicating that the minima and maxima hours presented in the predictive curve for all variables are weak and lack correlation between variables. A-P presents a good correlation (A-P, r<sup>2</sup> = 0.81), indicating that the minima and maxima predictive curve is good.

• = where significant differences were found between mean scores.

#### **7.4 Discussion:**

The aim of the present study was to investigate the temporal pattern of knee flexor eccentric strength at speeds of 60°·s<sup>-1</sup>, 150°·s<sup>-1</sup>, 300°·s<sup>-1</sup> and dynamic stability (OSI, A-P and M-L) post a soccer specific fatigue protocol that incorporated interchanges. This was to analyse what affect the interchanges within the SAFT<sup>90</sup> had on the temporal pattern of biomechanical function post fatigue. Currently this is an area that has not been implemented within soccer, so there is no research in this sport to date. It is a concept that is implemented within AFL and rugby league and has been researched in relation to its effect on non-contact musculoskeletal injury (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Sirotic et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013; Waldron et al., 2013; Black et al., 2013). Current research within these sports has shown that the implementation of interchange has had a positive effect on reducing the amount of non-contact musculoskeletal injuries (Gabbett.,

2005; Hoskins et al., 2006; Orchard et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013), which has been associated with a reduction of the acute physiological effects of fatigue (Sirotic et al., 2011; Waldron et al., 2013).

The temporal pattern post soccer specific fatigue was investigated in chapter 5. It is acknowledged that the subjects utilised in chapter 5 were not the same as in the present chapter, but players that completed the studies were from a similar level of professional football where the weekly demands of training and games were comparable. Difficulty exists in the recruitment of the same participants for these types of studies due to, too much time away from the club, but also when players are asked to refrain from training and gamely duties if the time period between studies becomes too long, players could exhibit decreased function and ability to recover due to detraining effects. Chapter 5 highlighted that biomechanical functions of eccentric hamstring strength and dynamic stability had not fully recovered at 72 hr. Comparisons will be made between the findings of the two studies to establish the influence interchange has on the acute effects of fatigue and the resultant 72 hr pattern.

#### ***7.4.1 Eccentric Strength:***

Mean scores displayed in in figure 10.1(a) and figure 10.2(a) highlight that the acute effects of fatigue elicited post the SAFT<sup>90</sup> with periods of interchange are comparable to players who complete the soccer specific fatigue protocols for a full 90 minutes, displaying reductions up to 25% (Greig., 2008; Greig et al., 2009; Small et al., 2009). This is an interesting finding, as the biomechanical measures display no differences by reducing the player's game time. This contradicts expected findings based on the research of Sirotic et al., (2011) and Waldron et al., (2013), who identified a reduction in the acute physiological effects of fatigue. Thus, suggesting that there are clear differences between physiological and biomechanical fatigue and the two potentially do not recover in a parallel fashion post event. It has been suggested what would be interpreted as minimal eccentric loading can actually induce the similar fatiguing effects as a game (Marshall et al., 2015).

Analysis of the results of the temporal pattern post fatigue highlight that when compared to baseline scores AvgPkt<sub>eccH</sub> at all speeds ( $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ) elicited contrasting findings. It can be seen that the slow and fast speeds indicated no significance at 72 hr post fatigue; thus, indicating recovery to baseline levels had been achieved. In addition, the mean

scores for the slow and fast speeds still demonstrate a reduction when compared to baseline and there was still a deficit. The mid speed ( $150^{\circ}\cdot\text{s}^{-1}$ ) demonstrated that when compared to baseline levels significant differences were displayed at all-time points indicating that functional strength of the hamstrings had not fully recovered. This was reiterated by the polynomial regression analysis that predicted that the baseline levels of AvgPkJ<sub>eccH</sub> and PkJ<sub>eccH</sub> would only return up to 82 hr post fatigue. Thus, indicating that despite the intervention of interchange the predicted recovery was comparable to that of chapter 4 and 5. Interestingly when looking at the post analysis of variance between time points for AvgPkJ<sub>eccH</sub> and PkJ<sub>eccH</sub> significant improvements in torque outputs were demonstrated by all speeds between 24 hr post fatigue and 72 hr. This suggests that significant recovery had taken place between this period and the period of no recovery identified in chapter 5, at 24 – 48 hr post fatigue has been accelerated by the use of interchange. Potentially suggesting that the DOMS affect post exercise had been reduced (Ernst., 1998; Cheung et al., 2003; Connolley et al., 2003; Micklewright., 2009; Nelson., 2013). It was also noted that no significant differences were identified at any time points when analysing  $^{\circ}\text{PkJ}_{\text{eccH}}$  at all testing speeds. Examination of the mean scores in figure 10.3 show that the angle increases and spikes immediately post fatigue and stays high at 24 hr post and then gradually declines again emphasising this 24 hr period post fatigue as the area where greatest deficits occur. This was consistent with the intervention of massage as a recovery tool in chapter 6. It is clear that although interchange had a positive effect over the temporal pattern in relation to significance values, mean values were still reduced and utilisation of the polynomial regression is highlighted again as a useful tool to highlight potential intervention in relation to recovery.

#### ***7.4.2 Dynamic Stability:***

Contrasting responses were displayed when analysing the results from the dynamic stability measures. Initial responses to fatigue demonstrated a decrease in stability performance across all measures (OSI, A-P and M-L), which is consistent with findings in current research (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). Again, it was noted that when looking at figure 6.4 it can be seen that the M-L scores are considerably better than the A-P scores through all testing time points, which emphasises potential differences between the afferent-efferent pathways of M-L and A-P stability (Zimny.,1988; Hogervorst et al., 1998; Greve., 1989; Haus et al., 1992;

Krauspe et al., 1995; Hogervorst et al., 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009) This also could be an indication of why the ACL and hamstring are more prone to injury as any EMD to initiated an efficient effective response may result in overstretch (hamstring injury) or increased load being exerted through the ACL, resulting in strain or potential rupture (Hewett et al., 1999; Laurin et al., 2011; Myer et al., 2012; Herman et al., 2012; Opar et al., 2012; Chen et al., 2013; Alentorn-Geli et al., 2015; Harput et al., 2015; Croix et al., 2015).

It was evident when analysing the variance between mean scores that the temporal pattern indicated that the intervention of interchange had some effect on the recovery post fatigue. A-P stability scores highlighted significant differences at all-time points except 72 hr post and M-L showed significance to 24 hr post. Polynomial regression analysis supports these findings as the predictive curve identifies the dynamic stability scores of M-L bottom by 16 hr, where the A-P scores remain consistent with the previous chapter (5) hitting a minima at 33.58 hr. It is noted that the predictive curve identifies that to return to baseline levels M-L took 31.99 hr and A-P took almost double the length of time at 67.16 hr. This again highlights the differences between A-P and M-L stability.

Analysis of the results exhibited post interchange suggests that either the actual decreases in stability as a result of fatigue were less or post the acute effects, where a large decline in stability scores was witnessed, that the longer-term effects of the fatigue are reduced. Potentially highlighting a decreased DOMS effect (Ernst., 1998; Cheung et al., 2003; Connolley et al., 2003; Micklewright., 2009; Nelson., 2013) or the reduction in eccentric loading brought about by the interchange has a reduced effect on the intrafusal fibres of muscle spindles or golgi tendon organs (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015), which has allowed for more efficient neuromuscular function.

### ***7.4.3 Synopsis:***

Effectiveness of interchange as an intervention strategy for reducing non-contact musculoskeletal injury has been shown to be successful within other sports (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Sirotic et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013; Waldron et al., 2013; Black et al., 2013) and thus it is suggested

that this could potentially be the case in football. This has been attributed to the fact that the physiological effects of fatigue are reduced (Sirotic et al., 2011; Waldron et al., 2013). The findings of the present study do support this is evident within dynamic stability measures. Hypothetically, the improvement of these biomechanical measures can be attributed to the reduced effect of fatigue on the intrafusal fibres in the muscle spindle and golgi tendon organs or the decreased inhibition of the mechanoreceptors within the knee joint (Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al., 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009).

The results from the present study indicate that the eccentric loading experienced by the hamstrings in the game has resulted in significant deficits in hamstrings strength that are consistent with previous research (Marshall et al., 2015). It is important to note that these reductions in strength have had no resultant effect on dynamic stability measures and that potentially the ability of the neuromuscular system and joint stabilisation of the knee is not reliant on the functional strength of the hamstrings. It is suggested that this would be a naïve assumption due to the nature of the BSS test. Although the test carried out is deemed functional in relation to it being completed on an unstable surface and through a closed kinetic chain, questions would be raised to how much functional strength would the player require to maintain stability. This does not discount from the findings in the present study as it is significant that the neuromuscular fatigue is decreased as a result of interchange; thus, increasing the player's ability to dynamically stabilise the knee joint. It merely suggests that if the player was to perform an activity that exposed the muscle to higher load and increased the demand placed on it would this then compromise the dynamic stabilisation of the joint.

Fatigue is a factor strongly associated with injury and the acute reduction in eccentric strength and dynamic stability is evident across research (Lattinziio et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Riberio et al., 2010; Thomas et al., 2010; Gear 2011; Changela et al., 2012). Game play is interspersed with periods of high intensity and low intensity bouts of exercise. It is within these high intensity bouts that players experience increased fatigue and this decreases muscular function (Mohr et al., 2003). Commonly both ACL and hamstring injuries are associated with deceleration or control of deceleration to accelerate off in an alternate direction, which these movement patterns are associated with high intensity exercise (Roberts et al., 2004; Vathrakokilis et al., 2008; Aletorn-Geli et al., 2009; Walden et al., 2011; Silva et al., 2012; Serpell et al., 2012; Shelbourne et al.,

2013; Hewett et al., 2013; Kim et al., 2016; Hyun-Jun et al., 2016). If these are continuously repeated and the intrafusal fibres are inhibited, resulting in EMD, then the athlete is more exposed to sustaining injury (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). Removal of the player during these periods of high intensity, or identification of when they are required to be removed via monitoring through GPS, is likely to reduce these effects and ultimately reduce the likelihood of sustaining injury. These reductions are demonstrated with the findings in the present study. It is important to note that these reductions maybe further increased by the introduction of a recovery intervention within these periods of interchange, and this could be a suggestion for further study. This would identify if these acute effects of fatigue could be further reduced. These findings highlight the need to explore the possible effects of rule change on non-contact musculoskeletal injury further and potentially suggest it could be utilised as a potential strategy for reducing hamstring and ACL injuries within the game.

## **7.5 Conclusion:**

Interchange as an intervention strategy had a positive effect on the temporal pattern of eccentric hamstrings PkT, AvgPkT and dynamic stability measures of OSI, A-P and M-L post soccer specific fatigue. This was particularly evident within the 24- 48 hr window where it had been previously identified that this was the period of stagnancy in relation to recovery (chapter 5). Differences were observed between the initial dynamic stability scores of A-P and M-L and the consequent results at subsequent time points. It was noted that the A-P scores were continuously worse than those of M-L. In addition to this angle of peak torque elicited no significant change through each time point. When analysing mean scores, acute responses indicated an increase in angle from baseline. It was noted that from time points 24 hr post and on to 72 hr post, this angle then remained consistent. The significance of these findings indicates the need for consideration of interchange as a potential rule change to help prevent the non-contact musculoskeletal injuries sustained in game play. Further research is suggested to identify if recovery strategies employed within the period of interchange would again reduce the temporal effect of fatigue. It is also noted that interchange applied within periods of fixture congestion could potentially reduce the risk of injury to players.

## **Chapter 8: General Discussion**

### **8.1 Introduction:**

The aim of this thesis was to investigate the 72 hr temporal pattern of eccentric strength ( $\text{AvgP}kT_{\text{eccH}}$ ,  $\text{P}kT_{\text{eccH}}$ ,  $^{\circ}\text{P}kT_{\text{eccH}}$ ) and dynamic stability (OSI, A-P and M-L) post localised hamstrings and soccer specific fatigue and utilise the findings from this research to guide intervention strategies and approach to monitoring the return to play of athletes. The final chapter of the thesis (Chapter 9) aims to synthesise the findings from the experimental studies to formulate conclusions and utilise these to direct proposals for future research.

Epidemiological research indicates that the incidence of hamstring (Woods et al., 2004; Arnason et al., 2008; Ekstrand et al., 2011) and ACL (Bjordal et al., 1997; Fauno et al., 2006; Walden et al., 2011; Serpell et al., 2012) injuries has not declined over the past decade, with suggestions in these papers indicating that these injuries have become more prominent in football. Similar aetiological factors have been associated with both injuries and have clearly been linked with fatigue, decreased eccentric (functional) strength and reduced dynamic stabilisation (Lattinzo et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Riberio et al., 2010; Thomas et al., 2010; Gear 2011; Changela et al., 2012). It is accepted within literature that the pre-cursors of non-contact musculoskeletal injury, such as hamstring and ACL injuries, are multi factorial (Askling et al., 2003; Hoskins., 2005; Pizzari et al., 2010; Mendiguchia et al., 2011; Opar et al., 2012). It is accepted, a deeper understanding of the temporal pattern post fatigue of these two main contributory factors is required.

Simple anatomical makeup of the medial hamstring muscles, understanding of the neuromuscular pathways and response to abnormal movement created from typical MOI's of the injuries formulate clear links between eccentric strength and dynamic stabilisation. To implement preventative strategies all models discussed earlier in the thesis highlight the need to identify the problem, apply an intervention, monitor the intervention strategy and make a judgement on its success (Van Mechelen et al., 1992; Finch., 2006; Verhagen et al., 2010). Successful implementation can only be achieved if full knowledge is ascertained. Current research has identified the effects of fatigue on eccentric strength and dynamic stabilisation, but is heavily focussed on the acute effects (Pincivero et al., 2000; Hiemstra et al., 2001;



Willems et al., 2002; Sangnieer et al., 2007; Ribeiro et al., 2008; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Torres et al., 2010; Ribeiro et al., 2010; Rampinini et al., 2011; Changela et al., 2012). The following discussion will highlight the temporal pattern post fatigue and how measures of eccentric strength and dynamic stability present over this 72 hr period. Highlighting, key differences and implications of findings on injury, intervention strategies and how the information can guide return to play criteria. The ability to predict periods of recovery and return to baseline levels will be discussed and the importance of this will be emphasised in relation to recovery strategies employed and key periods of where these should take place. This will give an indication of the importance of its use within the injury prevention model. The thesis and conclusions drawn from it will guide future practice with regards injury prevention strategies employed to combat the prevalence of hamstring and ACL injuries.

## **8.2 Influence of Fatigue:**

### **8.2.1 *Eccentric Strength:***

In order to establish the effect of fatigue on the hamstring muscle group a localised fatigue protocol was designed in Chapter 4 and completed on the IKD. The localised protocol was designed based on the work of Greig., (2008); Greig et al., (2009); Small et al., (2009) and Small et al., (2010). These papers identified a 20 – 30% decrease in  $PkT_{eccH}$  as a result of soccer specific fatigue across isokinetic speeds of  $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$  when tested on the IKD. These decreases in  $PkT_{eccH}$  were found immediately post fatigue and were identified as acute effects of fatigue on eccentric hamstring strength. The repeated bouts of eccentric work were completed at  $300^{\circ}\cdot s^{-1}$  until a decrease of 30% eccentric peak torque had been identified for three consecutive repetitions. Once this had been reached the fatigue protocol was complete. The justification for use of repeated high intensity contractions is associated with MOI for hamstring and ACL injuries (Roberts et al., 2004; Vathrakokilis et al., 2008; Aletorn-Geli et al., 2009; Walden et al., 2011; Silva et al., 2012; Serpell et al., 2012; Shelbourne et al., 2013; Hewett et al., 2013; Kim et al., 2016; Hyun-Jun et al., 2016), as these high intensity bouts are the ones most strongly associated with increased fatigue and reductions in muscular function (Mohr et al., 2003).

The results from Chapter 4 clearly identified that the acute effects exhibited post fatigue were consistent with previous research (Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Small et al., 2009; Small et al., 2010) and highlighted the susceptibility of the hamstrings to fatigue. Results also displayed that post fatigue and when monitoring the temporal pattern reductions were still exhibited at 72 hr post fatigue indicating that the eccentric strength of the athlete had not recovered and if exposed to high intensity work within this time frame they could be potentially exposing themselves to an increased chance of sustaining a non-contact musculoskeletal injury. These reductions were indicated at the mid and fast testing speeds ( $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ), which resemble the high intensity/speed work completed in game play associated with injury (acceleration/decelerations). It is suggested if the player's strength is reduced at these speeds, then they will expose the muscle to overload resulting in a hamstring tear or alternatively it will reduce its functional control of the knee and potentially increase the loads through the ACL resulting in damage to this main stabilising structure.

Regarding, limitations of the study presented in Chapter 4 it was acknowledged that the fatigue protocol was completed in an open kinetic chain, through one plane and repetitions were completed at one consistent high intensity speed of  $300^{\circ}\cdot s^{-1}$ . Arguably, this does not replicate the multi directional nature and impact experienced within game play. The purpose of the study was to highlight the effects of fatigue on the hamstring muscle group and the protocol completed was the most controlled way of isolating the muscles to determine this. The IKD is a tool commonly utilised in rehab due to its ability to isolate muscle groups and work them consistently through range and this provided the basis of justification for the use of this equipment. As stated earlier the high intensity speed of  $300^{\circ}\cdot s^{-1}$  was utilised to fatigue the athletes until a 30% reduction in  $PkT_{eccH}$  was achieved. Although, this continued repetition of high intensity contractions did elicit that 30% reduction in each player, it does not replicate the demands placed through the muscle in game scenarios. During games, players will be exposed to a variation of high intensity and low intensity bouts of exercise. It is suggested for future research that the fatigue protocol within the IKD could be designed to better replicate the demands on the muscle during game play. Identifying the number of decelerations an average player would experience during game play and completing these at high intensity, but also have periods of passive motion through the IKD that would replicate periods of low intensity. Ultimately, designing a protocol that has a variation of speeds of isokinetic contraction accompanied with periods of passive movements from the IKD that better replicate the demands experienced in game play.

Although limitations existed performing a localised fatigue protocol on the IKD it was noted that the similarity in reductions of functional hamstrings strength displayed similar findings to those of Greig., (2008) and Small et al., (2010) of a 20-30% decrease. More importantly, the acute effects monitored over a 72 hr temporal period displayed further reductions ( $\text{AvgPkJ}_{\text{eccH}60^\circ \cdot \text{s}^{-1}} = 19\%$  at 24 hr and 48 hr post;  $\text{AvgPkJ}_{\text{eccH}150^\circ \cdot \text{s}^{-1}} = 22$  and  $21\%$  at 24 hr and 48 hr post respectively;  $\text{AvgPkJ}_{\text{eccH}300^\circ \cdot \text{s}^{-1}} = 27\%$  at 24 and 48 hr post;  $\text{PkJ}_{\text{eccH}60^\circ \cdot \text{s}^{-1}} = 24\%$  and  $20\%$  at 24 hr and 48 hr post respectively;  $\text{PkJ}_{\text{eccH}150^\circ \cdot \text{s}^{-1}} = 19\%$  and  $16\%$  at 24 hr and 48 hr;  $\text{PkJ}_{\text{eccH}300^\circ \cdot \text{s}^{-1}} = 23\%$  and  $25\%$  at 24 hr and 48 hr). Identifying that the eccentric strength of the athlete bottomed at a point between 24 and 48 hr. Further analysis of the data through quadratic regression analysis indicated that this minima was displayed at (35 – 41 hr). The significance of this cannot be understated in football. Traditionally within clubs players will be given a day off after performance and back in to training 48 hr post performance. The results and conclusions drawn suggest special consideration needs to be given to the planning of training and recovery strategies implemented post game, as in periods of fixture congestion reductions in eccentric strength could potentially expose an athlete to injury.

Results and conclusions drawn from Chapter 5 were consistent with those of Chapter 4 highlighting the same acute responses in relation to eccentric strength post soccer specific fatigue and consistent with previous research (Greig., 2008; Greig et al., 2009; Small et al., 2009). The soccer specific fatigue protocol utilised within this study was the SAFT<sup>90</sup>, a multi directional protocol that replicated game specific movement patterns and is designed based on the demands placed on Championship level footballers in game play (Small et al., 2010). This protocol was specifically selected as it included the mutli-directional nature of game play, replicating movement patterns and intensities commonly associated with MOI of hamstring (Arnason et al., 2008; Engebretsen et al., 2010; Opar et al., 2012; Ekstrand et al., 2016) and ACL injuries (Bjordal et al., 1997; Bollen 2000; Fauno et al., 2006; Yu et al., 2007; Brophy et al., 2010). The main difference between the findings being that for the slow isokinetic speed of  $60^\circ \cdot \text{s}^{-1}$  significant differences ( $p \leq 0.05$ ) were displayed within soccer specific fatigue for all time points up to and including 72 hr when compared to baseline for  $\text{AvgPkJ}_{\text{eccH}}$  and  $\text{PkJ}_{\text{eccH}}$ , which was not reciprocated in the results of Chapter 4. It was noted that the mean scores ( $\text{AvgPkJ}_{\text{eccH}} - \text{Baseline } 118.63 \pm 23.8 \text{Nm}$  and  $72 \text{ hr post} = 107.13 \pm 20.3 \text{Nm}$  and  $\text{PkJ}_{\text{eccH}} - \text{Baseline } 150.08 \pm 32.68 \text{Nm}$  and  $72 \text{ hr post} = 131.29 \pm 28.01 \text{Nm}$ ) highlighted that there were still deficits in the slow speed results post-localised fatigue protocol. In addition observation of mean scores within the temporal pattern post fatigue displayed similar findings to chapter 4,

where reductions in eccentric strength bottomed between 24 and 48 hr ( $\text{AvgPkt}_{\text{eccH}60^\circ \cdot \text{s}^{-1}} = 19\%$  and  $18\%$  at 24 hr and 48 hr post respectively;  $\text{AvgPkt}_{\text{eccH}150^\circ \cdot \text{s}^{-1}} = 22$  and  $23\%$  at 24 hr and 48 hr post respectively;  $\text{AvgPkt}_{\text{eccH}300^\circ \cdot \text{s}^{-1}} = 25\%$  and  $26\%$  at 24 and 48 hr post respectively;  $\text{Pkt}_{\text{eccH}60^\circ \cdot \text{s}^{-1}} = 19\%$  and  $27\%$  at 24 hr and 48 hr post respectively;  $\text{Pkt}_{\text{eccH}150^\circ \cdot \text{s}^{-1}} = 20\%$  and  $25\%$  at 24 hr and 48 hr;  $\text{Pkt}_{\text{eccH}300^\circ \cdot \text{s}^{-1}} = 25\%$  and  $19\%$  at 24 hr and 48 hr respectively). . Quadratic regression analysis indicated that the minima of the curve was (35 – 41 hr) and maxima (71 – 82 hr). Again, indicating concerns within periods of fixture congestion. The importance of this information cannot be understated, as it would guide science and medicine staff at the club with regards planning and preparation, which includes recovery strategies, training design and consideration of player selection within periods of fixture congestion. Findings within chapter 4 and 5 indicate that the quadratic regression model used to predict the minima and maxima of curves within the temporal pattern of recovery could be utilised to predict a player's readiness for play. Future longitudinal research could include intergration of this monitoring tool within a season and conduct injury audits to ascertain its impact on reducing injury occurrence.

Interestingly,  $^\circ\text{Pkt}_{\text{eccH}}$  at all testing speeds displayed no significance when compared to baseline levels. When analysing players mean scores an increase in angle can be identified for all testing speeds across both chapters. These findings are consistent with the findings of Small et al., (2010), who demonstrated significant increases in angle through performance of the SAFT<sup>90</sup>. Although, conclusions drawn from the study were based on the acute effects of fatigue during a soccer specific protocol. There was no monitoring of the angle post fatigue. An increase in angle could potentially be a significant contributory factor to hamstring and ACL injury, due the player exhibited greater strength at shorter muscle lengths. This can be particularly problematic in a player's readiness for play in a period of fixture congestion if these angles remain high through the 72 hr temporal pattern. The increase in angle may implicate the function of the athlete and reductions in torque values at increased muscle length may result in the muscle being unable to withstand the load exerted during peromance and reduce its ability to functional stabilise the knee. This again is more supporting evidence for the impact fatigue has on muscle strength and function and how these reductions remain for a period post fatigue, potentially providing explanations of why players who play consecutively in periods of fixture congestion may sustain injury.

Throughout the discussion of the effects of fatigue and intervention strategies on the biomechanical marker of eccentric strength reference has been made between Chapters and comparisons of the results obtained. It is acknowledged that the same subjects were not utilised within Chapters 4 to 7. This was due to the time away from the club that players required to complete the studies and gaining access to elite footballers for this period of time can be difficult. It can also be problematic that players need to shut down from their normal daily training and game routine to complete the testing. If players completed consecutive studies then that would result in them not training or playing for a period of 3-4 weeks, which ultimately would result in potential deficits as a consequence of detraining. Alternatively, if there was a large period between testing of the players to be able to complete the studies then improvements or changes to the temporal pattern of recovery could have been attributed to training. Consideration also needed to be given to timing of the season when these studies were completed as focusses on training change and evolve through the year.

### ***8.2.2 Dynamic Stability:***

Clear links can be made between eccentric strength and dynamic stability purely by analysing neuromuscular anatomy and physiology. For the muscle to initiate an effected response the afferent-efferent neurological pathways and the mechanoreceptor detection initiating this process needs to be highly efficient (Owen et al., 2006; Moussa et al., 2009; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). If the muscle is strong eccentrically, but there is inhibition of this pathway then an EMD may occur, which results in an ineffective or delayed neuromuscular response (Ristanis., 2009; Esposito et al., 2010; Jensen et al., 2013; Conchola et al 2013; Warren et al., 2014; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). This may be sufficient enough to result in an overstretch of the hamstring resulting in a tear or abnormal movement occurring through the joint that could result in ACL rupture.

Research has highlighted this link by consistently showing that fatigue has acute detrimental effects on eccentric strength and dynamic stabilisation (Arnason et al., 2008; Greig., 2008; Ribeiro et al., 2008; Letafatkar et al., 2009; Henderson et al., 2009; Moussa et al., 2009; Wright et al., 2009; Small et al., 2010; Rampinini et al., 2011; Myer et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015). These effects have been solely analysed and emphasise the importance of increased knowledge of the 72 hr temporal pattern post fatigue. Earlier (9.2.1)

the temporal pattern of eccentric strength was discussed. Due to the multi factorial nature of hamstring and ACL injuries (Hawkins et al., 1999; Orchard et al., 2001; Hawkins et al., 2001; Renstrom et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Opar et al., 2012; Hewett et al., 2013; Ekstrand et al., 2016) and clear indications that fatigue, eccentric strength (Mair et al., 1996; Small et al., 2008; Greig., 2008; Greig et al., 2009; Small et al., 2009; Delextrat, 2010) and dynamic stabilisation (Askling et al., 2003; Arnason et al., 2008; Rees et al., 2008; Petersen et al., 2011) through performance are highlighted as key contributory factors, it is important to identify the temporal pattern of dynamic stability. This will then allow comparisons to be made in the synopsis.

Localised fatigue of the hamstring muscle group (Chapter 4) exhibited the same acute responses to fatigue as identified in previous research (Lattinzo et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Riberio et al., 2010; Thomas et al., 2010; Gear., 2011; Gioftsidou et al., 2011; Changela et al., 2012). Again, these responses indicated reductions in dynamic stability and these were most notable in OSI and A-P stability scores, where significant differences were found between all-time points up to 72 hr when compared to baseline. M-L stability scores indicated there were no significant differences at 72 hr post fatigue when compared to baseline, suggesting that these had recovered. It is important to note that the OSI stability scores are a combination of A-P and M-L stability and these provide an overview of overall stability through all planes. This OSI score can appear to be high when analysed on its own, but when looking at A-P and M-L scores visible differences may be presented to which stability measure is causing the OSI to be poor. It is evident within the present study when analysing the mean scores presented across all time points that the M-L stability scores were consistently and considerably less than those presented for A-P stability. This results in the conclusions drawn that A-P stability is affected more as a result of fatigue and this continues through the temporal pattern post fatigue.

The significance of these findings can be debated, but it is important to acknowledge that hamstring and ACL injuries are commonly sustained with movements that involve a deceleration through a sagittal plane (Hewett et al., 1999; Laurin et al., 2011; Myer et al., 2012; Herman et al., 2012; Chen et al., 2013; Alentorn-Geli et al., 2015; Harput et al., 2015; Croix et al., 2015). If detection of the golgi tendon organ or muscle spindle fails or there is an EMD this may result in overstretch (Ristanis., 2009; Esposto et al., 2010; Jensen et al., 2013; Conchola et al 2013; Ricci et al., 2014; Warren et al., 2014; Croix et al., 2015; Freddolini et al

2015). Alternatively, if the mechanoreceptors within the joint do not detect excessive anterior translation of the tibia and initiated an effected response to correct this, then this can result in increased load through the ACL, which may conclude with an ACL rupture (Ageberg et al., 2009; Yeow et al., 2013; Nacierio et al., 2013). Identification of the anatomical make up in relation to the mechanoreceptors within the joint may also explain why the M-L stability appears more responsive, as cardarvic research has shown that there are a reduced number of mechanoreceptors within the ACL (Zimny., 1988; Hogervorst et al., 1998; Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009). This could result in an EMD in terms of the afferent response and detection of excessive anterior translation. This said it is important to note that within this present study the fatigue was purely elicited through a sagittal plane, with repeated isokinetic eccentric contractions of the hamstring. This presents the question, could it be the case that fatigue purely through this plane has disrupted or desensitised the muscle spindles, golgi tendon organs and mechanoreceptors responsible for stability through this plane?

This is discounted by the results from Chapter 5 as they present similar findings to the results displayed in Chapter 4. Significant differences were found for all time points up to 72 hr post fatigue when compared to baseline for A-P stability. M-L stability showed no significant differences between baseline measures and 72 hr post fatigue indicating that this stability measure had recovered. Thus, discounting that localised fatigue (Chapter 4) through the sagittal plane disrupted or desensitised muscle spindles, golgi tendon organs or mechanoreceptors within the joint responsible for stability through this plane. This does credit the potential contribution of the mechanoreceptors within the joint and that the decreased amount of mechanoreceptors within the ACL could potentially contribute to an inhibited or slower afferent signal post detection of increased loading through the structure (Zimny.,1988; Hogervorst et al., 1998; Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009).

A major limitation within this present study and all research assessing proprioceptive or dynamic stabilisation responses (Ribeiro et al., 2008; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015) is that measurement of the afferent/efferent signals to detect which is delayed or working efficiently has not been done. Any measurement of this would be highly invasive and potentially damaging to the athlete being tested. Arguably, it is irrelevant and detection of the effected

response to abnormal or high loading is key (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). Understanding the influences of fatigue on this response is key to prevention of injury. Another limitation that is noted within the soccer specific fatigue protocol is that it does not incorporate any jumping or ball specific work. These movements within the game are predominantly completed on one leg and may result in bilateral differences between limbs, which may implicate increased fatigue to a unilateral limb. Further research containing soccer specific fatigue protocols should consider this and incorporate ball specific work and jumping activities. However, the present studies in to the influences of fatigue on dynamic stability and the 72 hr temporal pattern (Chapter 4 and 5) do emphasise significant reductions in stabilisation particularly within A-P stability and these findings have clear implications when formulating preventative or rehabilitative protocols. Results from chapters 4 and 5 also emphasise the importance of considering utilisation of dynamic stability measures as a marker for progression through a player's rehabilitation post injury. It could also formulate clear markers to indicate a player's readiness for more functional game specific activities.

Interestingly the results presented within Chapter 4 and 5 for the temporal pattern of eccentric strength and dynamic stability show very little recovery between time points 24 hr post fatigue and 72 hr. Polynomial regression analysis completed within both Chapters 4 and 5 highlight similar findings in relation to  $\text{AvgPkJ}_{\text{eccH}}$  and  $\text{PkJ}_{\text{eccH}}$  output. This predictive curve emphasises that the period where  $\text{AvgPkJ}_{\text{eccH}}$  and  $\text{PkJ}_{\text{eccH}}$  at all isokinetic speeds ( $60^{\circ}\cdot\text{s}^{-1}$ ,  $150^{\circ}\cdot\text{s}^{-1}$  and  $300^{\circ}\cdot\text{s}^{-1}$ ) bottom ranges between 35 and 42 hr with them only returning to baseline levels up to 82 hr post fatigue. Interestingly the polynomial regression analysis for dynamic stability scores within Chapters 4 and 5 elicited similar predictions. The stability scores (OSI, A-P, M-L) bottomed between 35 and 41 hr and only returned to baseline up to 81 hr post fatigue. The results exhibited within Chapters 4 and 5 accompanied with the predictive curves of the polynomial analysis highlight the need for intervention strategies to either reduce the effect of fatigue through therapeutic intervention or alternatively time exposed to fatiguing effects.



## **8.3 Interventions:**

### **8.3.1 *Eccentric Strength:***

Numerous recovery intervention strategies have been implemented within football in an attempt to decrease the incidence of non-contact musculoskeletal injuries like ACL and hamstring injuries (Davies et al., 2009; Gallaher et al., 2010; Duffield et al., 2010; Burgess., 2010; Lovell et al., 2011; Hill et al., 2013; Fonda et al., 2013; Pruscino et al., 2013; Hill et al., 2014; Hohenauer et al., 2015; Ferreira-Junioret al., 2015; Marques-Jimenez et al., 2016). Evidence highlights that these injuries are actually on the rise and have not declined over the past decade (Bjordal et al., 1997; Woods et al., 2004; Fauno et al., 2006; Arnason et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012). This potentially could be due to a lack of understanding of where these recovery strategies should be implemented and may explain why contradictory evidence has been presented in cryotherapy (Burgess., 2010; Fonda et al., 2013; Hohenauer et al., 2015; Ferreira-Junior et al., 2015), compression garments (Davies et al., 2009; Gallaher et al., 2010; Lovell et al., 2011; Pruscino et al., 2013; Hill et al., 2014; Marques-Jimenez et al., 2016) and soft tissue therapy (Tidus et al., 1995; Shoemaker et al., 1997; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Best et al., 2008; Brummitt et al., 2008; Nelson et al., 2013; Portilo-Soto et al., 2014) for recovery.

Chapter 6 analysed the effects of soft tissue massage implemented at 24 hr on the 72 hr temporal pattern post fatigue. The justification for implementation at this time point was based on the findings and regression analysis within Chapter 5, which examined the influences of fatigue on the 72 hr temporal pattern. It is important to note that the acute effects of fatigue were consistent with Chapters 4 and 5 and previous research within the area (Greig., 2008; Greig et al., 2009; Small et al., 2009). Results from the study highlighted that soft tissue therapy was an effective tool that accelerated recovery of player's post soccer specific fatigue. It was evident that post the intervention at 24 hr after the completion of the SAFT<sup>90</sup> there were significant increases in AvgPkJT<sub>eccH</sub> and PkJT<sub>eccH</sub> at all speeds ( $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ) when compared to time points 48 and 72 hr. Although these increases were found at 48 hr post fatigue the AvgPkJT<sub>eccH</sub> and PkJT<sub>eccH</sub> at all speeds ( $60^{\circ}\cdot s^{-1}$ ,  $150^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ) had not fully recovered and this was only achieved at 72 hr post fatigue ( $P \geq 0.05$  when compared to baseline).

Randomised controlled trials within the area of soft tissue therapy as a recovery tool has consistently shown that this is an effective intervention strategy (Rinder et al., 1995; Gupta et al., 1996; Farr et al., 2002; Robertson et al., 2004; Moraska., 2007). This has been attributed to the physiological effects of soft tissue application of increasing blood flow to encourage removal of fatiguing byproducts (Portillo-Soto et al., 2014; Petrosky et al., 2016). Another reason that has been presented in literature for the contradictory evidence presented in this field is the application of the soft tissue therapy (Petrofsky et al., 2008; Tew et al., 2010; Mori et al., 2014; Caldwell et al., 2016). It was noted in several studies that the experience of the clinician and techniques utilised within the recovery soft tissue work was not emphasised within the methods (Cafarelli 1990; Tidus et al., 1995; Shoemaker et al., 1997; Ernst., 1998; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010). This could have resulted in an ineffective recovery massage being completed to combat the effects of fatigue. The findings discussed in Chapter 6 utilised a clinician who has worked in elite sport for over 10 years and the techniques applied were consistent ensuring the depth of application was adjusted to suit the anatomical makeup of the player. All soft tissue therapy applied in previous research was also implemented immediately post fatigue. Arguably, at this stage heart rate and delivery of blood to the working tissues still remains high post activity and this will continue the supply of oxygen assisting the removal of fatiguing bi-products post activity. This is the underpinning theory for the application of massage as a recovery tool (Goats., 1994; Tidus et al., 1995; Shoemaker et al., 1997; Tidus., 1999; Hemmings., 2001; Ogai et al., 2008). Implicating that there may be no benefit to applying the massage immediately post fatigue. Analysis of the temporal patterns presented post fatigue and the regressions presented in Chapters 4 and 5 (figure 4.1(b), 4.2(b), 4.4(b), 5.1(b), 5.2(b) and 5.4(b)) support this notion, as they indicate no recovery between time points 24 and 48 hr post fatigue and they bottom between 35 and 42 hr post fatigue. Suggesting potential benefit to applying the massage at 24 hr post fatigue to try to accelerate or catalyse the recovery process between these two-time points. Results in Chapter 6 concluded that post massage there is a significant increase in AvgP<sub>KT<sub>eccH</sub></sub> and P<sub>KT<sub>eccH</sub></sub> at all speeds, but this was not an immediate acute effect, the benefits were only noticed 24 hr post massage (48 hr post soccer specific fatigue).

The results exhibited in Chapter 6 emphasise the importance of selection of when recovery strategies are implemented and this can be a key component in determining the effectiveness of the intervention. It also presents argument in the support of utilising soft tissue therapy as a

recovery tool within football post-game and if carefully periodised in to the training week within periods of fixture congestion can aid recovery of the player's eccentric strength in preparation for the next game. Suggestions for future research would be to analyse the effects of other recovery strategies on the 72 hr temporal pattern post fatigue, for example cryotherapy, compression garments and active recovery to name a few. Selection of where these recovery interventions are implemented will be based on the temporal pattern and the physiological justifications for use of these tools (Davies et al., 2009; Gallaher et al., 2010; Duffield et al., 2010; Burgess., 2010; Lovell et al., 2011; Fonda et al., 2013; Pruscino et al., 2013; Hill et al., 2013; Hill et al., 2014; Hohenauer et al., 2015; Ferreira-Junior et al., 2015; Marques-Jimenez et al., 2016). Successful implementation of soft tissue therapy as a recovery tool also has potential to be utilised as a preventative measure to aid reduction of non-contact musculoskeletal injuries, such as ACL and hamstring injuries based on models listed in literature (Van Mechelen et al., 1992; Finch., 2006; Verhagen et al., 2010). It is accepted that approaches to prevention of hamstring and ACL injuries needs to be multi-modal (Hawkins et al., 1999; Orchard et al., 2001; Hawkins et al., 2001; Renstrom et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Hewett et al., 2013; Ekstrand et al., 2016) and clear indication within research and the current thesis indicate that key contributory factors are fatigue, eccentric strength and dynamic stabilisation (Arnason et al., 2008; Letafatkar et al., 2009; Henderson et al., 2009; Pizzari et al., 2010; Moussa et al., 2009; Myer et al., 2012; Opar et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015; Ekstrand et al., 2016).

Another intervention strategy that has been successfully implemented within other sports is the interchange rule (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Sirotic et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013; Waldron et al., 2013; Black et al., 2013). This rule has been successfully introduced in sports like AFL and rugby league to reduce non-contact musculoskeletal injury (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013). Literature has also indicated that the interchange rule has had a positive influence on the acute physiological effects of fatigue (Sirotic et al., 2011; Waldron et al., 2013). Chapter 7 investigated the effects of interchange on the temporal pattern of soccer specific fatigue. The acute effects of fatigue in relation to  $\text{AvgPkT}_{\text{eccH}}$  and  $\text{PkT}_{\text{eccH}}$  post interchange were comparable to previous research analysing the acute effects of fatigue over 90 mins (Greig., 2008; Greig et al., 2009; Small., et al., 2009) and consistent with the results from Chapters 4, 5 and 6. The biomechanical measures utilised in this study and previous chapters contradicted the acute physiological effects and conclusions

drawn by Sirotic et al., (2011) and Waldron et al., (2013). This potentially emphasises that physiological fatigue and biomechanical fatigue are not comparable and it is suggested that these could potentially replicate two very different gauges of a person's response to football specific activity. It is therefore suggested that future research could consider monitoring player's temporal pattern post fatigue utilising both biomechanical and physiological measures to determine if the pattern of recovery varies. It is important to consider the psychological effects of fatigue that could be represented within strength measures. If a player perceives that they are tired, weak or sore then potentially their torque output could be less. This said Marshall et al., (2015) indicated that a single set of 5 repetitions elicited similar acute fatigue effects on eccentric and concentric torque values of the hamstring muscle group, as were exhibited post a 90-minute protocol. Interestingly this study was completed on amateur footballers and it would be assumed that professional player's may have increased fatigue resistance to this type of training, as it would be something they complete within their weekly routine as a professional. This said, findings cannot be discounted and further research completed on elite players would be warranted and this could include monitoring the temporal pattern post fatigue.

Results from Chapter 7 indicated contrasting findings to previous research in rugby league and AFL (Gabbett., 2005; Hoskins et al., 2006; Orchard et al., 2011; Orchard., 2012; Orchard et al., 2012; Orchard et al., 2013), but also within the study itself. The slow and fast speed ( $60^{\circ}\cdot s^{-1}$  and  $300^{\circ}\cdot s^{-1}$ ) significance scores indicated that at 72 hr post fatigue recovery had been achieved, when compared to baseline. When analysing the mean scores this highlighted deficits were still presented at 72 hr post. The mid speed of  $150^{\circ}\cdot s^{-1}$  indicated that at 72 hr post fatigue significant differences were still found when compared to baseline, indicating the players had not fully recovered.

These findings tentatively provide support to the paper by Marshall et al., (2015) and provide further justification for more research in this area, as the results show the same acute effects of fatigue as exhibited in Chapters 4, 5 and 6. Utilisation of the findings in this paper and conclusions drawn from Chapter 7 indicate that the 60 mins of game play contained significant enough eccentric loading on the hamstrings to create similar fatiguing effects to the previous chapters and research (Greig., 2008; Greig et al., 2009; Small et al., 2009). Further analysis of the findings within Chapter 8 highlighted significant improvements in eccentric strength scores between time point's 24 hr post and 72 hr post. This potentially indicates that the DOMS effect post exercise had been reduced, due to the reduction in playing time (Ernst., 1998; Cheung et

al., 2003; Connolley et al., 2003; Micklewright., 2009; Nelson., 2013). Conclusions drawn, indicate that this period between time points 24 hr post and 48 hr post that was previously identified as being stagnant and a period where minimal recovery had taken place had actually been improved with the introduction of interchange. Justification to why this is the case is unknown. Although the acute effects of fatigue within this chapter were consistent with previous research, the temporal pattern had been altered and again supports the need for further study.

### ***8.3.2 Dynamic Stability:***

As discussed earlier, dynamic stabilisation is reliant on two factors good functional eccentric control and an efficient neuromuscular pathway (Ristanis., 2009; Esposto et al., 2010; Jensen et al., 2013; Conchola et al 2013; Warren et al., 2014; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). Chapters 4 and 5 demonstrated that the temporal pattern post fatigue resulted in significant deficits in dynamic stabilisation and this was related to the desensitisation of disruption of the mechanoreceptors (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). It is commonplace within all sports to implement recovery strategies to reduce the effects of fatigue post event (Davies et al., 2009; Gallaher et al., 2010; Duffield et al., 2010; Burgess., 2010; Lovell et al., 2011; Hill et al., 2013; Fonda et al., 2013; Pruscino et al., 2013; Hill et al., 2014; Hohenauer et al., 2015; Ferreira-Junior et al., 2015; Marques-Jimenez et al., 2016).

One of the most common strategies implemented is the use of soft tissue therapy (Cafarelli 1990; Tidus et al., 1995; Shoemaker et al., 1997; Ernst., 1998; Galloway et al., 2004; Moraska 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). This research highlights inconsistencies exist within literature and practice, in relation to techniques utilised, when it should be implemented and how. The multi factorial nature of injury prevention (Hawkins et al., 1999; Orchard et al., 2001; Hawkins et al., 2001; Renstrom et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Opar et al., 2012; Hewett et al., 2013; Ekstrand et al., 2016) highlights the need to identify the effect of soft tissue therapy on dynamic stabilisation in conjunction with eccentric strength post soccer specific fatigue.

Dynamic stabilisation has been shown to be significantly negatively affected post soccer specific fatigue (Chapter 5) and this is consistent with previous research (Lattinzo et al., 1997; Meznyk et al., 2006; Riberio et al., 2008; Riberio et al., 2010; Thomas et al., 2010; Gear., 2011; Gioftsidou et al., 2011; Changela et al., 2012), so any intervention strategy that reduces these effects would be a positive preventative strategy. Findings from Chapter 6 indicate that this is the case and results indicate that implementation of soft tissue therapy at the right time point post fatigue can have a positive influence on the temporal pattern of recovery post fatigue in relation to dynamic stability. Indirectly this could have a positive effect on the incidence of non-contact musculoskeletal injuries such as ACL and hamstring injuries, as it has been shown to reduce the effects of fatigue and accelerate recovery (Chapter 6).

Results from Chapter 6 highlighted that the acute effects of fatigue on dynamic stability were consistent with previous research (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015) and Chapters 4 and 5. It was also found that the dynamic stability measures of A-P were consistently worse than the M-L measures through all time points. Evidently, when analysing the temporal pattern in Chapters 4 and 5 it could be seen that there was very little recovery taking place between time points 24 hr post fatigue and 72 hr post. Based on these findings and the predictive curve exhibited by the polynomial regression analysis it was decided that soft tissue therapy would be implemented at this stage to see if it accelerated the recovery post this time point. Conclusions drawn within this chapter highlighted that the soft tissue therapy resulted in recovery of M-L stability measures immediately post massage and A-P measures were recovered at 48 hr post fatigue. These differences between M-L and A-P stability scores again highlight potential exposure to the structures that are at risk through sagittal plane movements when controlling movement patterns that involve high deceleration loading (Hewett et al., 1999; Laurin et al., 2011; Myer et al., 2012; Herman et al., 2012; Chen et al., 2013; Alentorn-Geli et al., 2015; Harput et al., 2015; Croix et al., 2015). It was also highlighted that from pre massage to 48 hr post fatigue for all time points that significant improvements were made in all stability measures for time points 24 hr post fatigue and pre massage to 48 hr post fatigue.

The significance of these findings highlights the effectiveness of soft tissue therapy as a recovery tool and the importance of utilisation of this within a period of fixture congestion. The positive results obtained were attributed to the study addressing issues highlighted in

previous research of inconsistencies within techniques utilised, poor application due to the inexperience of the clinician, time administered for and when the therapy was applied (Petrofsky et al., 2008; Tew et al., 2010; Wiltshire et al., 2010; Nedelec et al., 2013; Mori et al., 2014; Caldwell et al., 2016). This was a major strength of the study as application of the massage was delivered by a clinician who has 10 years plus experience of soft tissue therapy in elite sport and the control of the techniques utilised, length of time delivered and the specificity of delivery to the player (see Chapter 6.2.3) were consistent in each treatment. The selection of the massage techniques was also based on the principles of sports massage and the claimed benefits of applying these techniques within a recovery session (Goats., 1994; Tidus et al., 1995; Shoemaker et al., 1997; Tidus., 1999; Hemmings., 2001; Ogai et al., 2008). Physiologically, application of soft tissue therapy is predominantly based around the notion that blood flow is increased to the tissues. This supplies more oxygen to the area and increases lymphatic drainage to aid the removal of fatiguing by products (Ernst 1998; Zainuddin et al., 2005; Weerapong et al., 2005; Zainuddin et al., 2005; Best et al., 2008; Brummitt et al., 2008; Micklewright 2009; Wiltshire et al., 2010; Nelson et al., 2013; Portilo-Soto et al., 2014). The findings in chapter 6 support that potentially this is the case. However, due to no physiological measures being taken during this study it is not conclusive that this was the case. Further research in this area is required and it is suggested that future design should incorporate physiological measures alongside the biomechanical measures taken.

Chapters 4 and 5 indicated clear links between deficits in eccentric strength and dynamic stabilisation, indicating a similar period of recovery post fatigue, but also highlighting comparable points within the 24 hr pattern where reductions in them peak. Chapter 7 again indicated that the reductions in A-P stability were consistently lower than M-L stability at all-time points measured from baseline to 72 hr post fatigue. This again strengthens the argument that there is reduced efficiency within the afferent-efferent pathway related to A-P stability than there is with M-L stability (Zimny.,1988; Hogervorst et al., 1998; Greve., 1989; Haus et al., 1992; Krauspe et al., 1995; Hogervorst et al, 1998; Georgoulis et al., 2001; Lee et al., 2008; Adachi et al., 2009). Analysis, of this in relation to the anatomical contribution of the hamstring could potentially be extremely significant.

The semitendinosus and semimembranosus muscles are key stabilisers within the knee joint and have a large role in contributing to reducing the amount of anterior tibial translation exerted through the knee joint when decelerating and changing direction quickly (Feagin et al., 1985;

Boden et al., 2000; Fauno et al., 2006; Yu et al., 2007; Holly et al., 2011; Bryant et al., 2011; Levine et al., 2012; Serpell et al., 2012. This movement pattern in football has been commonly associated with ACL injury (Walden et al., 2011; Serpell et al., 2012; Hewett et al., 2013). It is suggested that if there is a delay within this effected response when performing these movements and these muscles do not initiate a response in time. This will exert more stress through the ACL and this could result in ACL rupture. Alternatively, the most common muscle torn within the hamstring group is biceps femoris (De Smet et al., 2000; Koulouris et al., 2003; Woods et al., 2004). Discussions in literature have indicated that this may be the case because this muscle has dual nerve innervation and there is potentially an EMD within effected response because of this (De Smet et al., 2000; Koulouris et al., 2003; Woods et al., 2004). To look at this in relation to dynamic stabilisation and the results achieved across all chapters, it is suggested the muscles that are least respondent are the semitendinosus and semimembranosus. This is due to the poor A-P scores elicited in all results across Chapters 4, 5, 6 and 7. It is suggested that the efficiency of the mechanoreceptors and the afferent signal may be the result of an EMD, as a result the biceps femoris increases in activation to try to restrict the movement of overload and because the muscle cannot withstand the load exerted on it this results in a tear.

The acute fatigue effects exhibited by the results in Chapter 7 were consistent with previous research (Hiemstra et al., 2001; Owen et al., 2006; Ribeiro et al., 2008; Moezy et al., 2008; Moussa et al., 2009; Torres et al., 2010; Ribeiro et al., 2010; Torres et al., 2010; Changela et al., 2012; Cordeiro et al., 2014; Lee et al., 2015). The temporal pattern post fatigue with an intervention of interchange displayed significant effect on recovery post fatigue. The most notable effect was within M-L stability that indicated that this had recovered at 24 hr post fatigue. A-P recovered 48 hr post and OSI indicated that it had not recovered and was significantly reduced at all-time points when compared to baseline. This indicates that interchange had a positive effect on the dynamic stabilisation scores. Again the differences and consistently better scores attributed to M-L stability when compared to A-P strengthen argument that the M-L afferent-efferent pathway is more efficient. This efficiency will ultimately dictate the effected response of the hamstring muscle group and any delay may result in one of the muscles having increased load exerted through it or the ACL may be exposed due to a lack of functional control from the semitendinosus and semimembranosus muscles, as previously discussed. Regardless of the strength of the hamstring muscle group if the neuromuscular response is not efficient then the strength becomes irrelevant and the functional control will be reduced or non-existent.



Interestingly the improvements exhibited within the dynamic stability measures post soft tissue massage and interchange, were supported by the predictive curve produced in the polynomial regressions. They both demonstrated that all measures of stability had returned to baseline levels at 67 hr post fatigue. Interestingly the predictive curve for interchange signified large reductions in the time period it took the curve to reach a minima and huge differences were exhibited between A-P and M-L stability, with the A-P minima at 33.58 hr and M-L at 16.00 hr. There is argument to suggest that the improvements in dynamic stability can be associated with the nature of the BSS test and that if a test that exerted increased loads through the joint were conducted then this may change the findings. This said the differences between A-P and M-L stability cannot go unnoticed and argument to whether the decreased mechanoreceptors within the ACL could contribute to this or could it be as simple as a result of fatigue the athlete unconsciously loads through this A-P plane and forces the tilt of the platform in this direction. To explore this further, it is suggested that research is continued incorporating a different dynamic stability test and potentially looking at the single leg hop and hold as this will elicit more force through the stabilising tissue and joint and the direction of loading will be responsive to the movement pattern of the individual.

#### **8.4 Practical Implications:**

Reviewing the results from each individual study allow development of intervention strategies to attempt to reduce hamstring and ACL injuries, which despite all current interventions implemented over the last decade have not decreased (Bjordal et al., 1997; Woods et al., 2004; Fauno et al., 2006; Arnason et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012). As described in preventative models within research, the issue must be highlighted, intervention implemented and then effect of the intervention monitored (Van Mechelen et al., 1992; Finch., 2006; Verhagen et al., 2010). The current thesis introduces a predictive model of recovery post fatigue using a quadratic regression. This analysis allows identification of a predictive minima and maxima of the recovery curve within the 72 hr temporal pattern. Within each study, this quadratic regression analysis has been applied. The minima of the curve in chapters 4 and 5 was utilised to identify where recovery had bottomed and potentially where intervention should be applied. This minima was identified at 35 – 41 hr and guided the time of intervention of soft tissue massage applied in chapter 6. Having the ability to predict deficits and recovery profiles of players allows medical and science staff to identify the effectiveness of any interventions applied, with two used in the current thesis (chapter 6 and 7). Having

information on the time periods of recovery and likely patterns of players can also be utilised to individualise training strategies and recovery methods employed; veering practice in the field away from a 'one size fits all' approach.

It is common within football for players to experience periods of fixture congestion and potentially these periods could contribute to an increased chance of injury. Aetiological research has detailed factors contributing to both ACL and hamstring injuries are multi factorial (Hawkins et al., 1999; Orchard et al., 2001; Hawkins et al., 2001; Renstrom et al., 2008; Ekstrand et al., 2011; Walden et al., 2011; Serpell et al., 2012; Opar et al., 2012; Hewett et al., 2013; Ekstrand et al., 2016), with recent research highlighting the main factors contributing being fatigue and its effect on eccentric strength and dynamic stabilisation (Arnason et al., 2008; Letafatkar et al., 2009; Henderson et al., 2009; Pizzari et al., 2010; Moussa et al., 2009; Myer et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015; Ekstrand et al., 2016). Literature commonly has been heavily focussed on the acute effects of fatigue on eccentric strength (Pincivero et al., 2000; Willems et al., 2002; Sangnieer et al., 2007; Greig., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Rampinini et al., 2011) and dynamic stabilisation (Hiemstra et al., 2001; Ribeiro et al., 2008; Torres et al., 2010; Ribeiro et al., 2010; Changela et al., 2012), both of which have been shown to reduce as a result of fatigue. It is these reductions within these biomechanical measures that have been attributed to sustaining non-contact musculoskeletal injury. Although, these findings identify a problem they do not develop discussion for use in prevention and all research listed above focuses on a unilateral problem and does not address the multi factorial issue associated with injury.

The current body of work within the thesis heavily focuses on the temporal pattern of fatigue and its effect on eccentric strength and dynamic stabilisation. Chapters 4 and 5 highlight the influences of fatigue and address how localised fatigue of the hamstring effects these biomechanical measures and how this compares to soccer specific fatigue respectively. Focus on basic anatomy and physiological function clearly highlights a link between eccentric strength and dynamic stabilisation. Theorising, that deficits will be displayed within both measures if neuromuscular function is not efficient. Conclusions drawn from both of these chapters support this. Analysis of the results within both studies and how fatigue affects eccentric strength and dynamic stability demonstrate acute reductions within both, which are consistent with previous research (Pincivero et al., 2000; Hiemstra et al., 2001; Willems et al.,

2002; Sangnieer et al., 2007; Greig., 2008; Ribeiro et al., 2008; Greig et al., 2009; Wright et al., 2009; Small et al., 2009; Small et al., 2010; Thomas et al., 2010; Torres et al., 2010; Ribeiro et al., 2010; Rampinini et al., 2011; Changela et al., 2012). It was also identified that these reductions remain through the 72 hr temporal pattern post fatigue. In addition, when analysing the results in relation to dynamic stability the A-P scores were consistently lower than OSI and M-L.

Hamstring and ACL injuries can have distinct similarities within the MOI, as both can occur through a sagittal plane as a result of rapid deceleration (hamstring injuries - Orchard et al., 1997; Woods et al., 2004; Gabbe et al., 2006; Arnason et al., 2008; Engebretsen et al., 2010; Pizzari et al., 2010; Mackey et al., 2011; Opar et al., 2012; Mendiguchia et al., 2012; Serpell et al., 2012; Ropiak et al., 2012; Orchard et al., 2012; Ekstrand et al., 2016 and ACL injuries - Bjordal et al., 1997; Bollen 2000; Fauno et al., 2006; Yu et al., 2007; Brophy et al., 2010). Clear links to the two injuries can be made and the results from all studies within the thesis support this. Results in all chapters' highlight consistently that the A-P stability scores are always consistently higher than M-L scores, indicating poorer A-P stability in players.

Questions remain over whether it is reduction in eccentric strength as a result of fatigue that contributes to decreases in player's ability to stabilise the joint through movement or is it a result of desensitisation of the mechanoreceptors that the afferent-efferent signal causes an EMD and thus the effected output is decreased? A limitation of each study within this thesis (Chapters 4, 5, 6 and 7) and the others in the field before it (Hiemstra et al., 2001; Ribeiro et al., 2008; Torres et al., 2010; Ribeiro et al., 2010; Changela et al., 2012) is that the afferent-efferent signal cannot be measured, identification of whether an EMD had occurred or where this EMD occurred would detail exactly what was causing the reduction in eccentric strength and resultant dynamic stabilisation. Establishing this within research would require the study design to be highly invasive and arguably, the information received would not implicate the approach to developing injury prevention strategies. Research has indicated that the EMD is created by disruption and desensitisation of the intrafusal fibres within the muscle tissue or the mechanoreceptors within the joint (Pedersen et al., 1999; Ristanis., 2009; Torres et al., 2010; Conchola et al 2013; Ricci et al., 2014; Croix et al., 2015; Freddolini et al 2015). Arguably, it is irrelevant where this EMD is generated and the most important thing is that it is identified that players are experiencing this EMD, as this can then be utilised as a marker of injury. Implementation of eccentric strength and dynamic stability measures could be implemented

post-game to identify a player's readiness for the next fixture or training. They could also be utilised as markers in periodised training to increase a player's fatigue resistance, ultimately allowing them to maintain eccentric strength and dynamic stability measures.

This has been highlighted by Blanch et al., (2015) and Hulin et al., (2015) who emphasise the importance of knowing what to do and when. The findings from Chapters 4 and 5 develop underpinning knowledge of when intervention strategies are required. These papers discussed the importance of managing the acute: chronic workload ratio and indicated this could be predicted. They predicted this for elite sportsman to be 0.85:1.35 and identified players who could manage this were safe to return to sport and at a decreased risk of injury. This research also suggests that if the acute effects of fatigue can be controlled or reduced then this allows the athlete to continue to work, which ultimately will increase fatigue resistance and will result in them being less likely to sustaining injury. Conclusions drawn, potentially explain why the intervention strategy of applying interchange had limited effect on the temporal pattern of eccentric strength and A-P dynamic stability scores. If the players could not achieve an acute: chronic workload of 0.85:1.35 prior to the study then the work completed within the 60 minutes of game time would elicit the same biomechanical fatigue response, as if they were completing a 90 minute game (Marshall., et al., 2015). Thus creating a similar temporal pattern post fatigue for eccentric strength and dynamic stability. Therefore, future research in this area would require establishment of the players acute: chronic workload ratio prior to testing, as this could potentially effect output received when monitoring the temporal pattern.

Management of the acute workload and the effects on eccentric strength and dynamic stability were achieved by the intervention of soft tissue therapy. Regression analysis of the temporal pattern post soccer specific fatigue (Chapter 5) highlighted that eccentric strength and dynamic stability scores bottomed between 35 and 42 hr. Supporting the  $AvgP_kT_{eccH}$  and  $P_kT_{eccH}$  results indicating there was very little recovery between time points 24 hr and 48 hr post fatigue. This provided the underpinning justification for applying an intervention of soft tissue therapy at 24 hr to accelerate this recovery. This was achieved and improvements in eccentric strength and dynamic stability were achieved. These findings are significant as the regression analysis completed enables a prediction to be made of where the eccentric strength and dynamic stability scores are at their lowest, indicating where interventions that are aimed to accelerate recovery would be best applied. This would enable medical teams to identify intervention strategies that

aid the management of fatigue and ultimately keep the acute: chronic workloads balanced, as this has been shown to reduce injury (Blanch et al., 2015; Hulin et al., 2015).

Further research in this field would be best focussed on analysing the effects of other intervention strategies on the temporal pattern post fatigue. Fatigue as a result of game play is an unalterable factor and as little as 1 set of 5 repetitions of Nordic hamstring curls have been shown to elicit a significant decrease in muscular function post completion (Marshall et al., 2015). This emphasises that management of the acute effects of fatigue will balance the acute: chronic workload ratio (Hulin et al., 2015; Blanch et al., 2016). It would be unrealistic and impractical to suggest from these findings that players should not play within the 72 hr window post fatigue, because deficits in eccentric strength and dynamic stability were still exhibited. Careful consideration needs to be given to what is completed the next day post-game play and how training is managed over the period of 72 hr. There are many intervention strategies that have been applied within football as an aid of recovery (Davies et al., 2009; Gallaher et al., 2010; Duffield et al., 2010; Burgess., 2010; Lovell et al., 2011; Hill et al., 2013; Fonda et al., 2013; Pruscino et al., 2013; Hill et al., 2014; Hohenauer et al., 2015; Ferreira-Junior et al., 2015; Marques-Jimenez et al., 2016). Justification for why research in these strategies is inconclusive is due to the lack of understanding of where they should be implemented. These recovery interventions utilised include active recovery, cryotherapy and compression garments to name a few and future research could focus on how the application of these interventions effect the management of the acute: chronic workload ratio, but more specifically how would they affect the temporal pattern post fatigue. Other considerations that need to be made in future study is combining physiological measures with biomechanical measures and track the temporal pattern of each. This would allow conclusions to be drawn to whether the physiological response to game specific fatigue marries with the biomechanical recovery. A final consideration of any future research is to utilise the same group of players with a predetermined acute: chronic workload ratio. This would allow for definitive conclusions to be drawn on the effectiveness of potential interventions and comparisons to be directly made. Each of the studies within the thesis utilised a different group of players and thus would only allow suggestive comparisons to be made between the studies.

## 8.5 Conclusions

Hamstring (Woods et al., 2004; Arnason et al., 2008; Ekstrand et al., 2011, Ekstrand et al., 2016) and ACL injuries (Bjordal et al., 1997; Fauno et al., 2006; Walden et al., 2011; Serpell et al., 2012, Walden et al., 2016) are on the rise within football and are resulting in significant financial costs to clubs (Woods et al., 2002; Rahnema et al., 2002; Murphy et al., 2003; Verrall et al., 2006). Evidently key contributory factors to these injuries are eccentric hamstring strength, dynamic stability and fatigue (Arnason et al., 2008; Letafatkar et al., 2009; Henderson et al., 2009; Pizzari et al., 2010; Moussa et al., 2009; Myer et al., 2012; Alentorn-Geli et al., 2015; Croix et al., 2015; Ekstrand et al., 2016).

Conclusions drawn within the thesis indicate that the hamstring is a key muscle in supporting and stabilising the knee when performing functional game activity. Any deficits in neuromuscular function of the hamstrings result in decreased strength and dynamic stability being exhibited. Thus, increasing the potential for injury to the hamstring muscles or the ACL as a stabilising structure within the knee. Experimental studies 1 and 2 (Chapters 4 and 5) demonstrate similar findings in relation to the 72 hr temporal patterns of biomechanical measures post fatigue. They both highlight significant reductions in relation to  $\text{AvgPkT}_{\text{eccH}}$ ,  $\text{PkT}_{\text{eccH}}$  and dynamic stability scores post localised and soccer specific fatigue, with recovery not taking place up to 82.03 and 81.23 hr respectively. Indicating that in periods of fixture congestion athletes may be more susceptible to injury. Although, non-significance was found for the temporal pattern of the  $^{\circ}\text{PkT}_{\text{eccH}}$  within both chapter 4 and 5 similar patterns emerged where the angle increased through the 72 hr period, indicating that the hamstring could be more prone to injury when functional load is applied. Importantly, these two chapters emphasise the importance of a predictive model that indicates a player's readiness for play in periods of fixture congestion, as it can guide training and recovery strategies employed.

It is evident that the implementation of soft tissue massage post soccer specific fatigue had a positive effect on the temporal pattern post fatigue as measures of  $\text{AvgPkT}_{\text{eccH}}$ ,  $\text{PkT}_{\text{eccH}}$  and dynamic stability scores had all fully recovered by 72 hr, suggesting a readiness to play the next fixture. Manipulation of the fatigue exerted on the athlete by means of periods of interchange had limited effect on player's temporal pattern with analysis highlighting this could take up to 82.13 hr post. This emphasises the need to focus on the conditioning of the player and preparation in relation to recovery strategies to enable them to be ready for the next game.

The need for management of the acute: chronic workload exerted on players within periodised plans (Blanch et al., 2015; Hulin et al., 2015) is a key factor in preventing injury.

The findings within the thesis develops understanding of how fatigue effects key aetiological contributing factors to injury, but also increases knowledge of the chance of injury within periods of fixture congestion (72 hr temporal pattern). Evidence has been presented supporting the use of quadratic regression analysis to predict periods of recovery post fatigue and inform the timing of impletmentation of recovery or intervention strategies.

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**Appendices:**

**Appendix 1: Example of Statistical Analysis Utilised in Each Study:**

**1.1: PkT60 Localised Boxplot**

```
EXAMINE VARIABLES=PreTPk postTPk Post24TPk Post48TPk Post72TPk
/COMPARE VARIABLE
/PLOT=BOXPLOT
/STATISTICS=NONE
/NOTOTAL
/MISSING=LISTWISE.
```

**Explore**

**Notes**

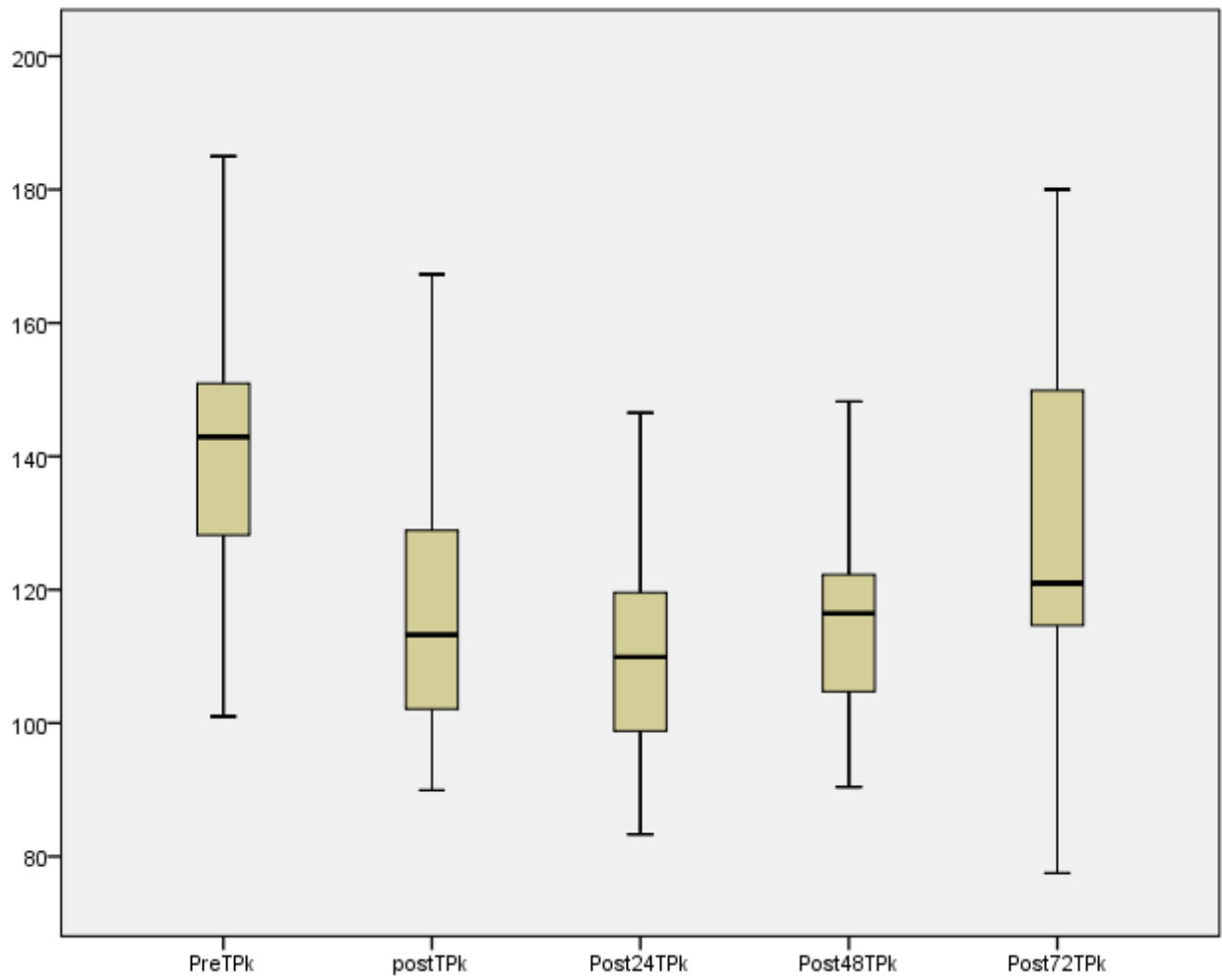
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Comments		
Input	Data	/Users/Rhodesy/Documents/ Hard Drive/Sports Therapy Uni Work/Research/PhD Data/Final Results/SPSS Data/Localised/60 localised.sav
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	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	18
Missing Value Handling	Definition of Missing	User-defined missing values for dependent variables are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any dependent variable or factor used.

Syntax		EXAMINE VARIABLES=PreTPk postTPk Post24TPk Post48TPk Post72TPk /COMPARE VARIABLE /PLOT=BOXPLOT /STATISTICS=NONE /NOTOTAL /MISSING=LISTWISE.
Resources	Processor Time	00:00:00.17
	Elapsed Time	00:00:00.00

**Case Processing Summary**

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
PreTPk	18	100.0%	0	0.0%	18	100.0%
postTPk	18	100.0%	0	0.0%	18	100.0%
Post24TPk	18	100.0%	0	0.0%	18	100.0%
Post48TPk	18	100.0%	0	0.0%	18	100.0%
Post72TPk	18	100.0%	0	0.0%	18	100.0%





**1.2: PkT60 Localised QQ Plot:**

GET

FILE='/Users/Rhodesy/Documents/Hard Drive/Sports Therapy Uni Work/Research/PhD Data/Final Results/SPSS Data/Localised/60 localised.sav'.

DATASET NAME DataSet4 WINDOW=FRONT.

DATASET ACTIVATE DataSet4.

DATASET CLOSE DataSet3.

PLOT

/VARIABLES=PreTav postTav Post24Tav Post48Tav Post72Tav PreTPk postTPk Post24TPk Post48TPk Post72TPk PreAngle PostAngle Post24Angle Post48TAngle Post72TAngle

/NOLOG

/NOSTANDARDIZE

/TYPE=Q-Q

/FRACTION=BLOM

/TIES=MEAN

/DIST=NORMAL.

**PPlot**

**Notes**

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Comments		
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	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	18
	Date	<none>
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	For a given sequence or time series variable, cases with missing values are not used in the analysis. Cases with negative or zero values are also not used, if the log transform is requested.

Syntax		P PLOT /VARIABLES=PreTA <sub>v</sub> postTA <sub>v</sub> Post24TA <sub>v</sub> Post48TA <sub>v</sub> Post72TA <sub>v</sub> PreTP <sub>k</sub> postTP <sub>k</sub> Post24TP <sub>k</sub> Post48TP <sub>k</sub> Post72TP <sub>k</sub> PreAngle PostAngle Post24Angle Post48TAngle Post72TAngle /NOLOG /NOSTANDARDIZE /TYPE=Q-Q /FRACTION=BLOM /TIES=MEAN /DIST=NORMAL.
Resources	Processor Time	00:00:03.99
	Elapsed Time	00:00:05.00
Use	From	First observation
	To	Last observation
Time Series Settings (TSET)	Amount of Output	PRINT = DEFAULT
	Saving New Variables	NEWVAR = CURRENT
	Maximum Number of Lags in Autocorrelation or Partial	MXAUTO = 16
	Autocorrelation Plots	
	Maximum Number of Lags Per Cross- Correlation Plots	MXCROSS = 7
	Maximum Number of New Variables Generated Per Procedure	MXNEWVAR = 60
	Maximum Number of New Cases Per Procedure	MXPREDICT = 1000
	Treatment of User- Missing Values	MISSING = EXCLUDE
	Confidence Interval Percentage Value	CIN = 95
	Tolerance for Entering Variables in Regression Equations	TOLER = .0001
	Maximum Iterative Parameter Change	CNVERGE = .001

Method of Calculating Std. Errors for Autocorrelations	ACFSE = IND
Length of Seasonal Period	Unspecified
Variable Whose Values Label Observations in Plots	Unspecified
Equations Include	CONSTANT

### Model Description

Model Name	MOD_2	
Series or Sequence	1	PreTAv
	2	postTav
	3	Post24TAv
	4	Post48TAv
	5	Post72TAv
	6	PreTPk
	7	postTPk
	8	Post24TPk
	9	Post48TPk
	10	Post72TPk
	11	PreAngle
	12	PostAngle
	13	Post24Angle
	14	Post48TAngle
	15	Post72TAngle
Transformation	None	
Non-Seasonal Differencing	0	
Seasonal Differencing	0	
Length of Seasonal Period	No periodicity	
Standardization	Not applied	
Distribution	Type	Normal
	Location	estimated
	Scale	estimated
Fractional Rank Estimation Method	Blom's	
Rank Assigned to Ties	Mean rank of tied values	

Applying the model specifications from MOD\_2

### Case Processing Summary

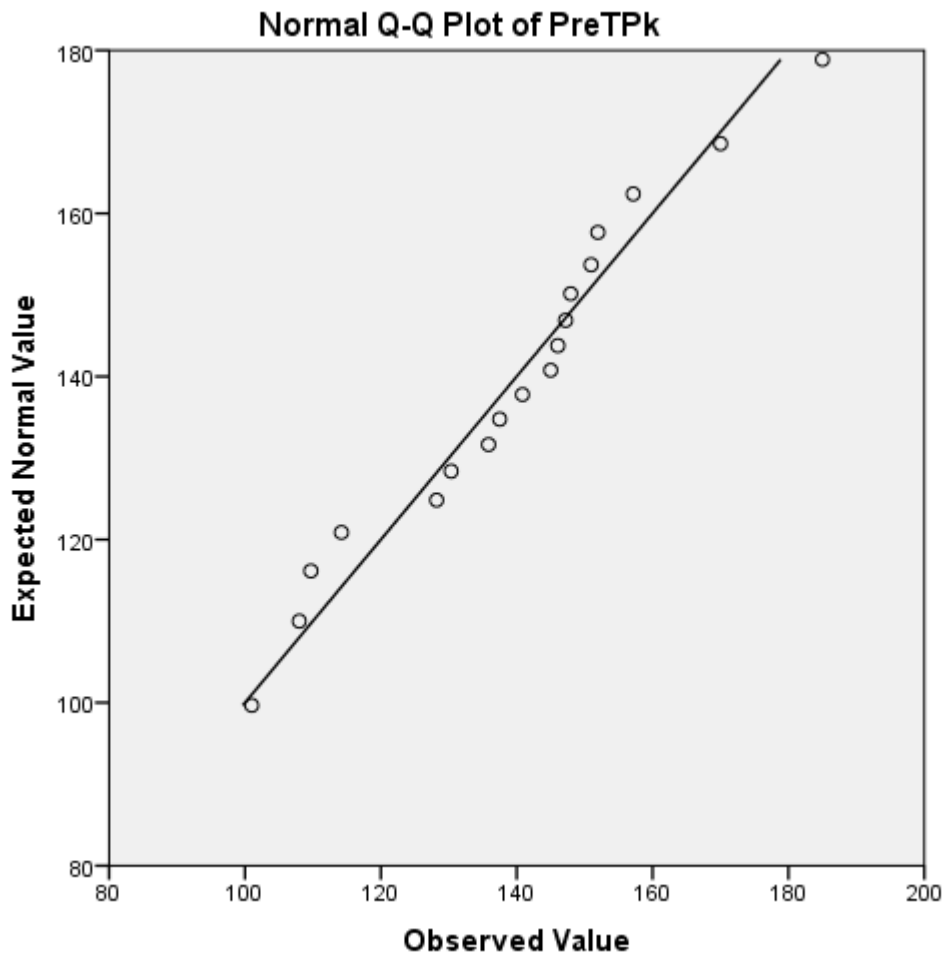
	Pre TA v	pos tTa v	Post 24T Av	Post 48T Av	Post 72T Av	Pre TP k	pos tTP k	Post 24T Pk	Post 48T Pk	Post 72T Pk	Pre Ang le	Post Ang le	Post2 4Ang le	Post48 TAngl e	Post72 TAngl e
Series or Sequenc e Length Nu Us mb er er Mi of ssi Mi ng ssi Sys ng tem Val - ues Mi in ssi the ng Plot	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

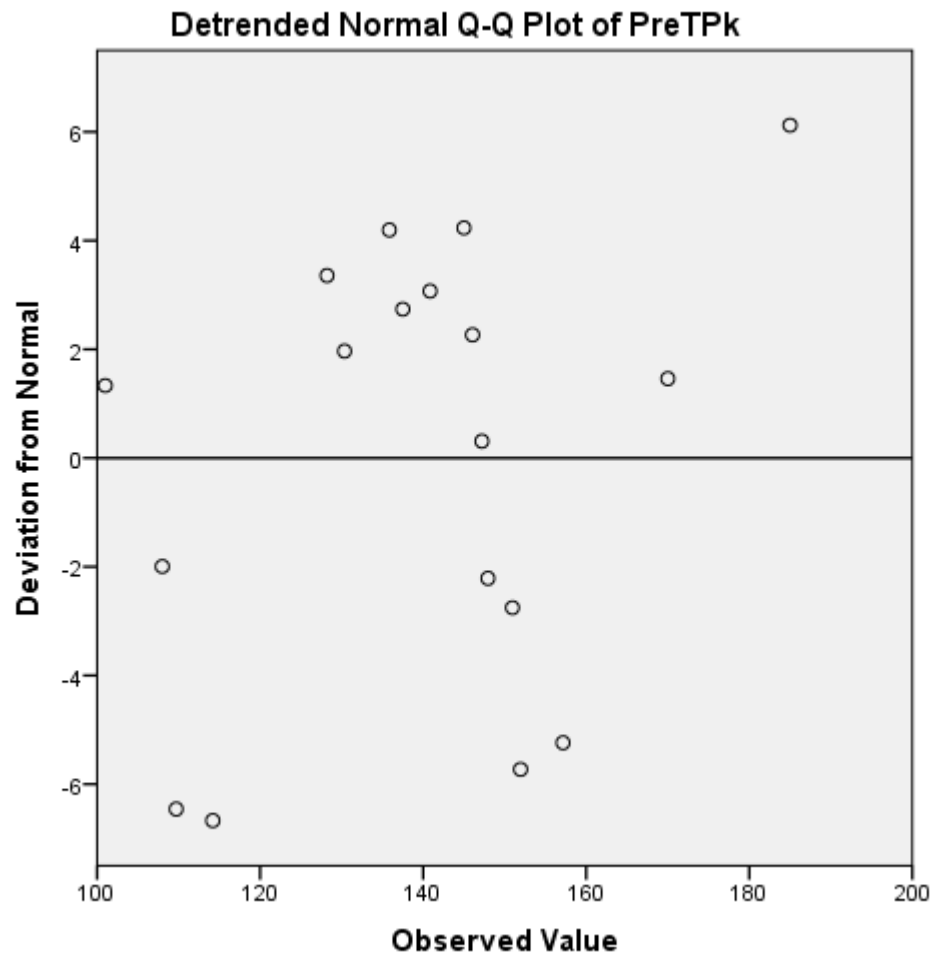
The cases are unweighted.

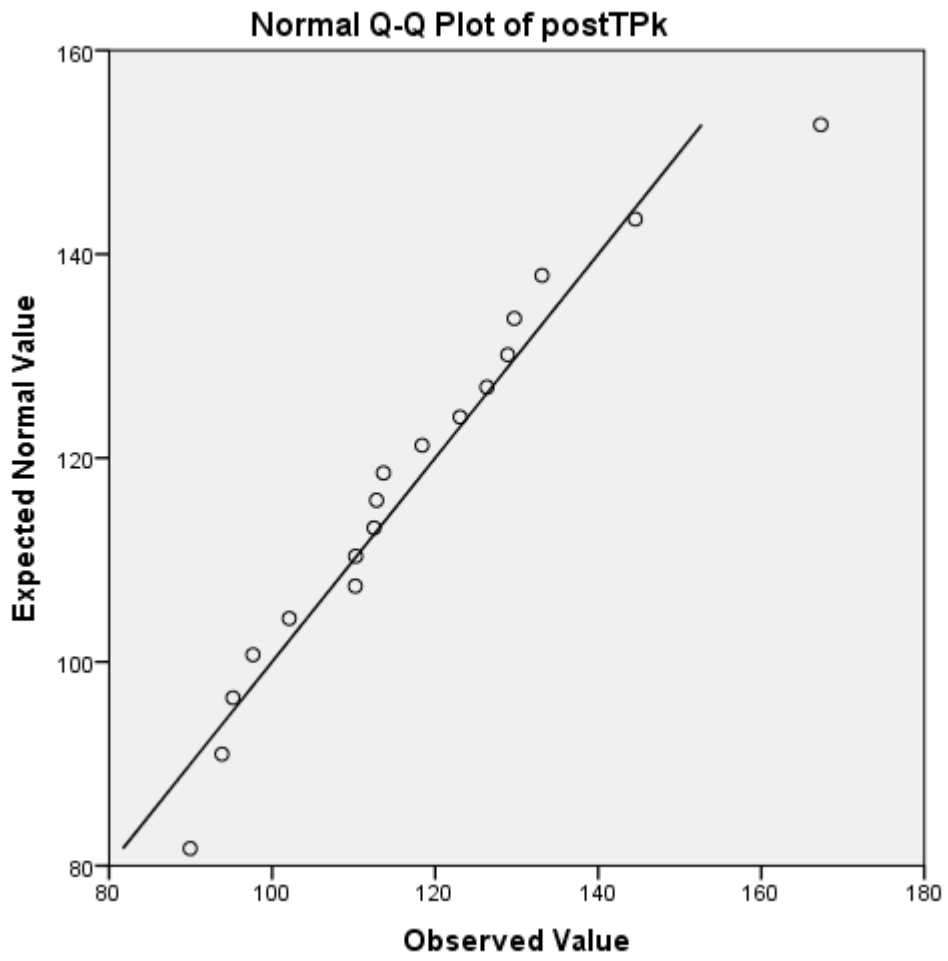
#### Estimated Distribution Parameters

	Pre TA v	pos tTa v	Post 24T Av	Post 48T Av	Post 72T Av	Pre TP k	pos tTP k	Post 24T Pk	Post 48T Pk	Post 72T Pk	Pre An gle	Post Ang le	Post2 4Ang le	Post4 8TAn gle	Post7 2TAn gle
Nor Lo mal cati Distr on ibuti Sca on le	114 .32 06	94. 644 6	92.1 065	92.6 003	102. 8057	139 .27 28	117 .19 44	109. 205 6	115. 377 8	126. 805 6	39. 666 7	50.1 667	54.19 44	64.36 11	49.50 00
	19. 107 31	15. 173 13	15.0 9313	14.2 1359	17.1 9407	21. 740 23	19. 488 64	16.0 511 9	14.8 203 1	24.5 395 8	16. 796 36	25.5 216 2	21.51 411	25.86 549	24.64 513

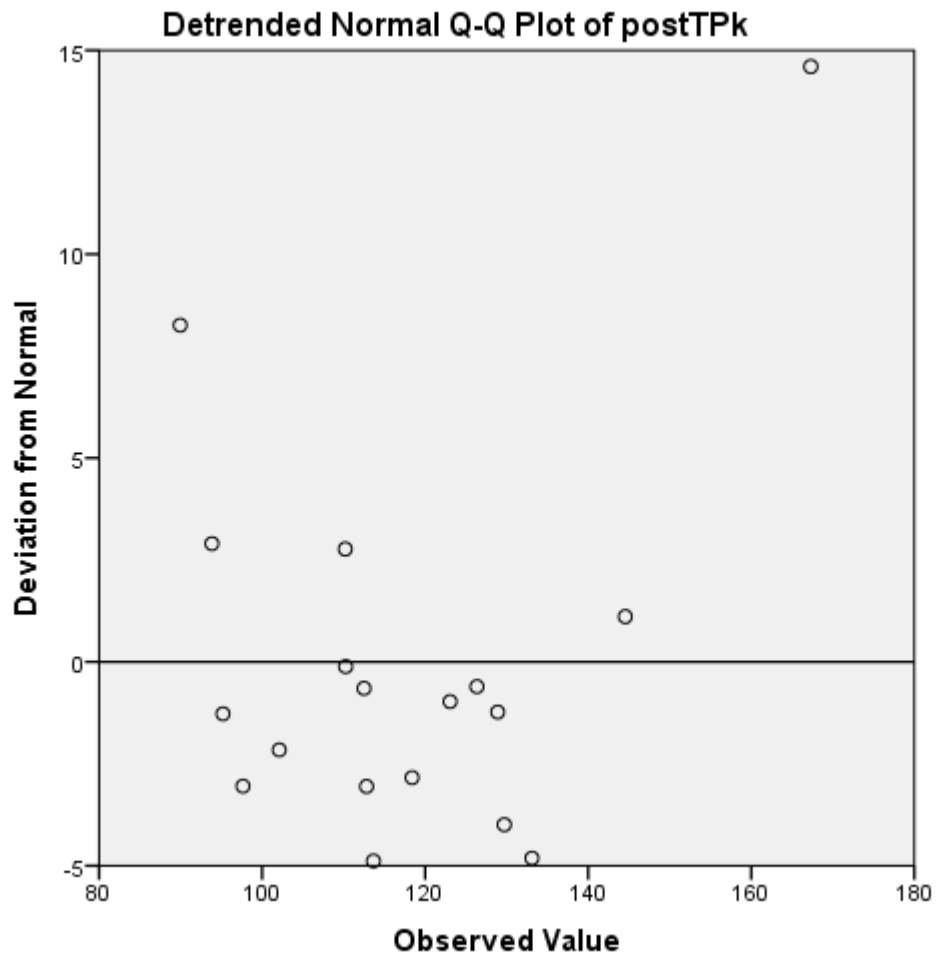
The cases are unweighted.

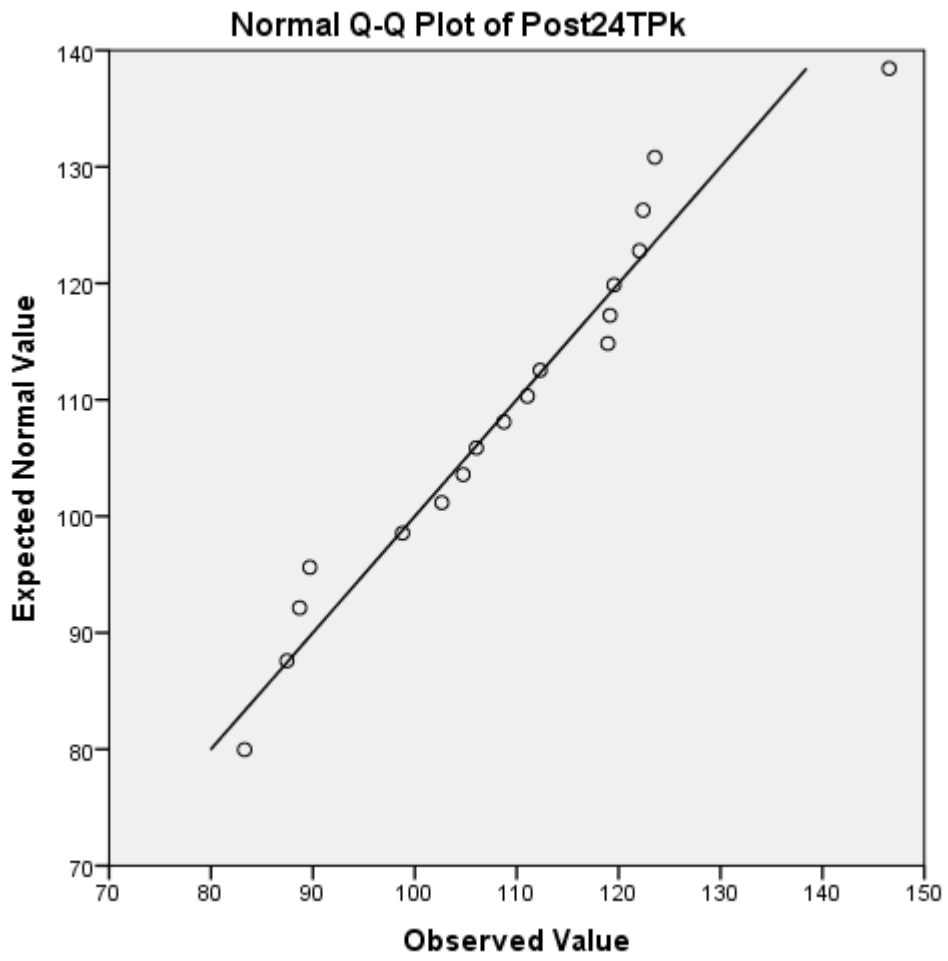


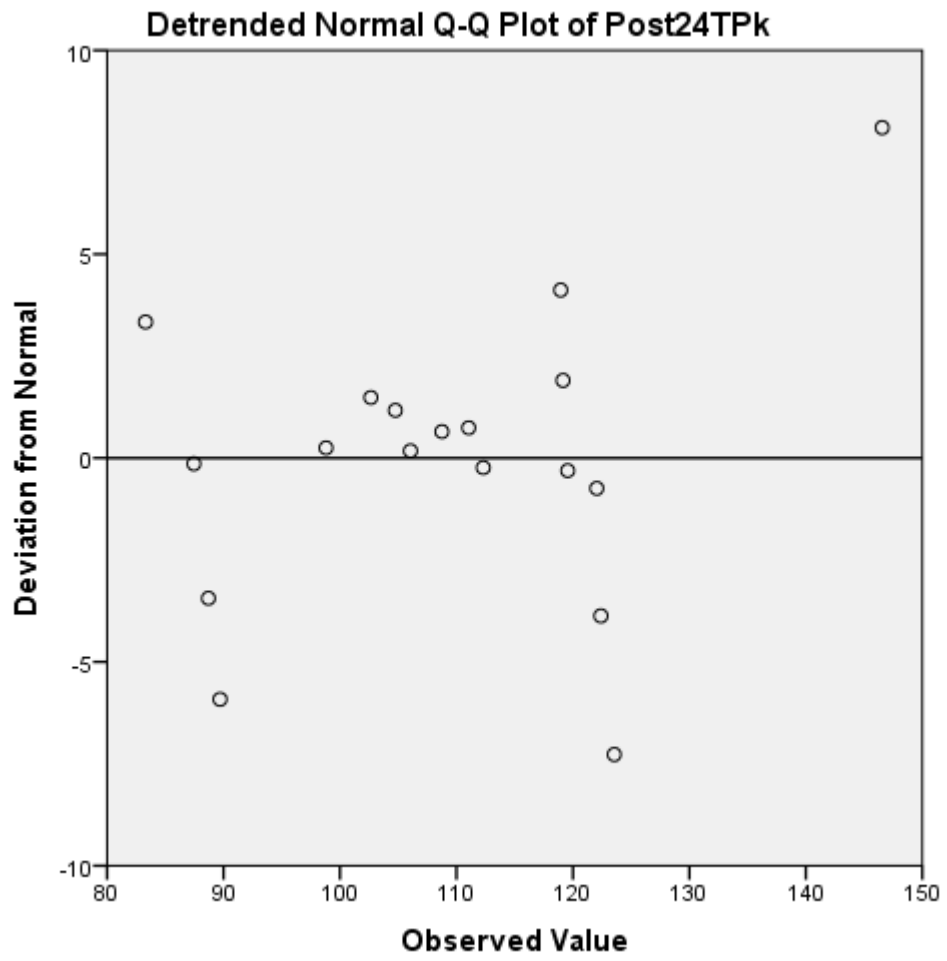


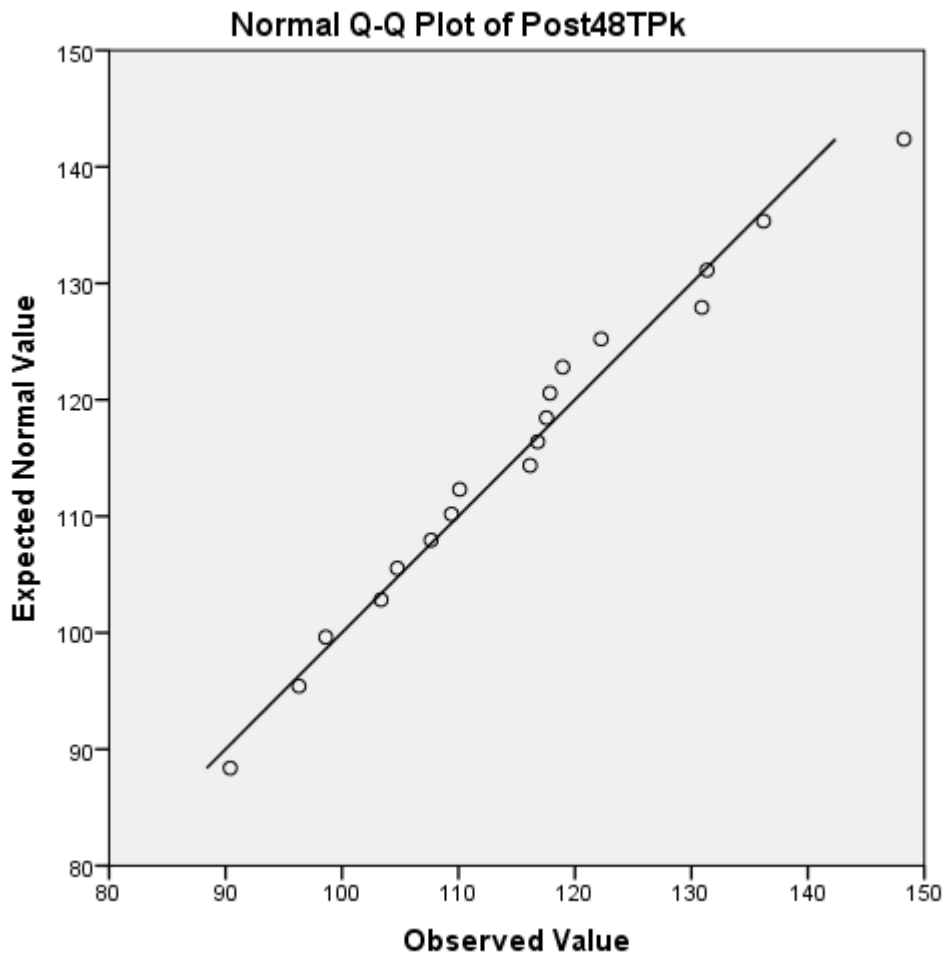


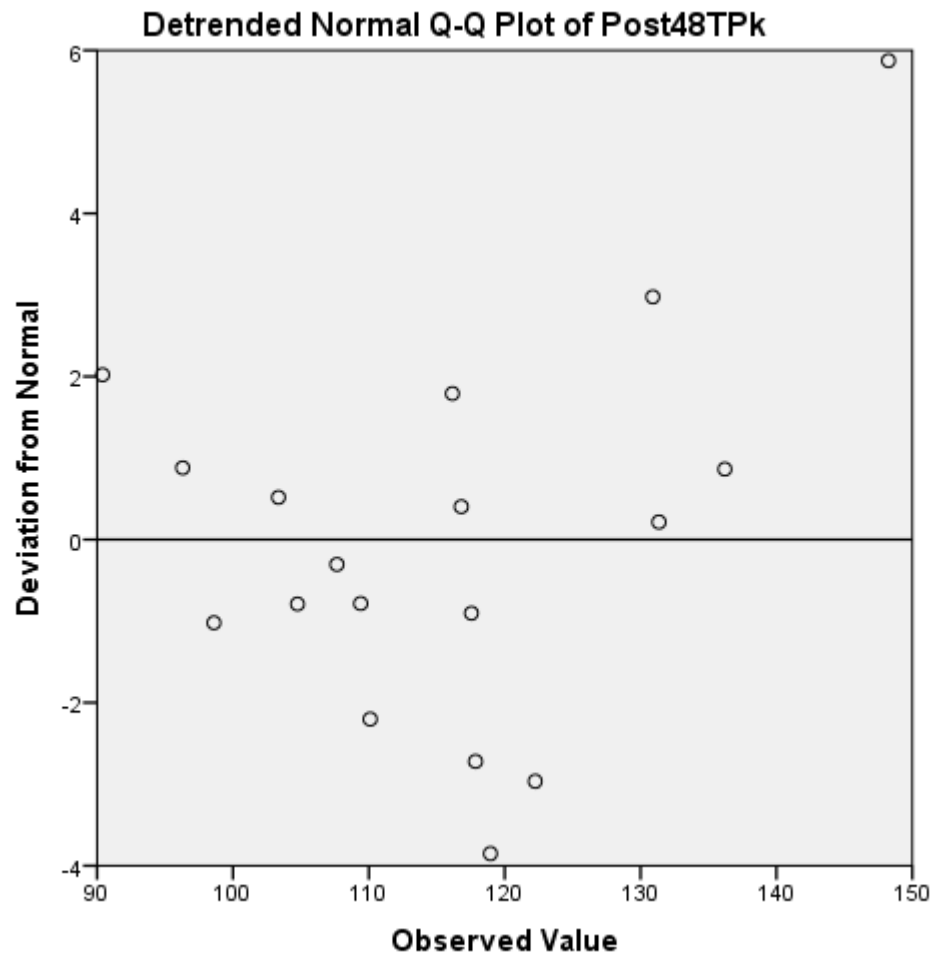


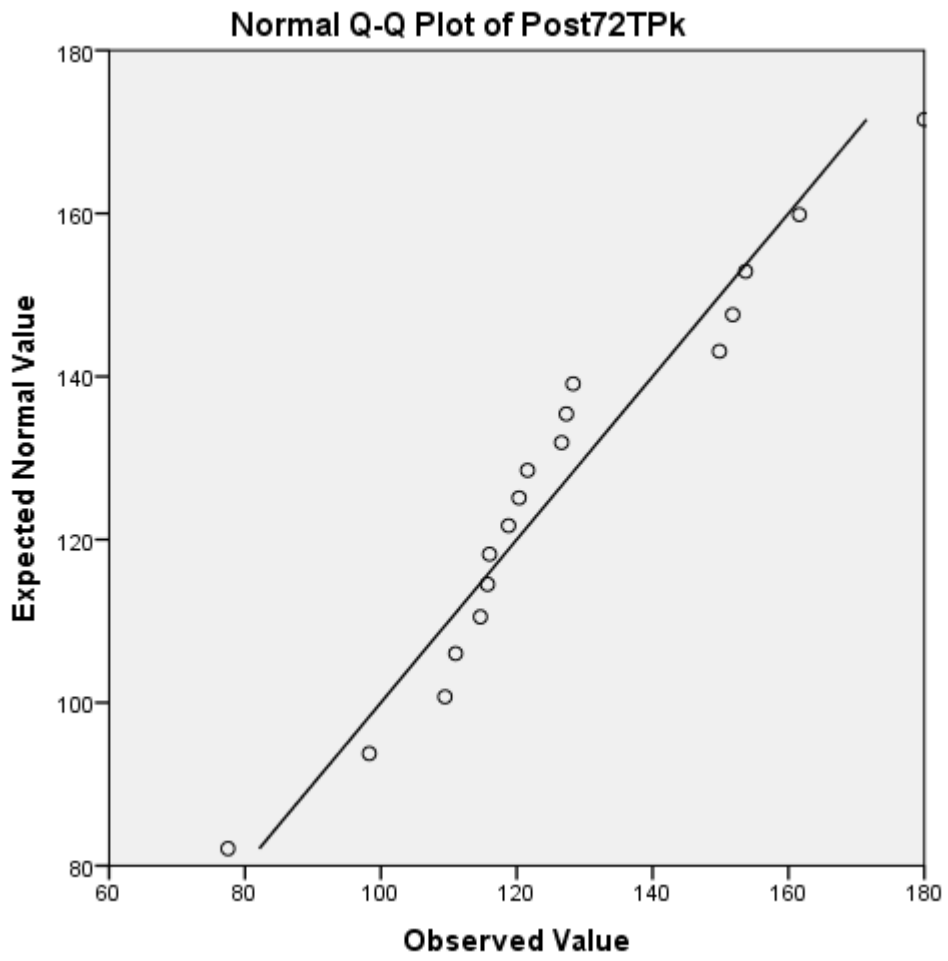


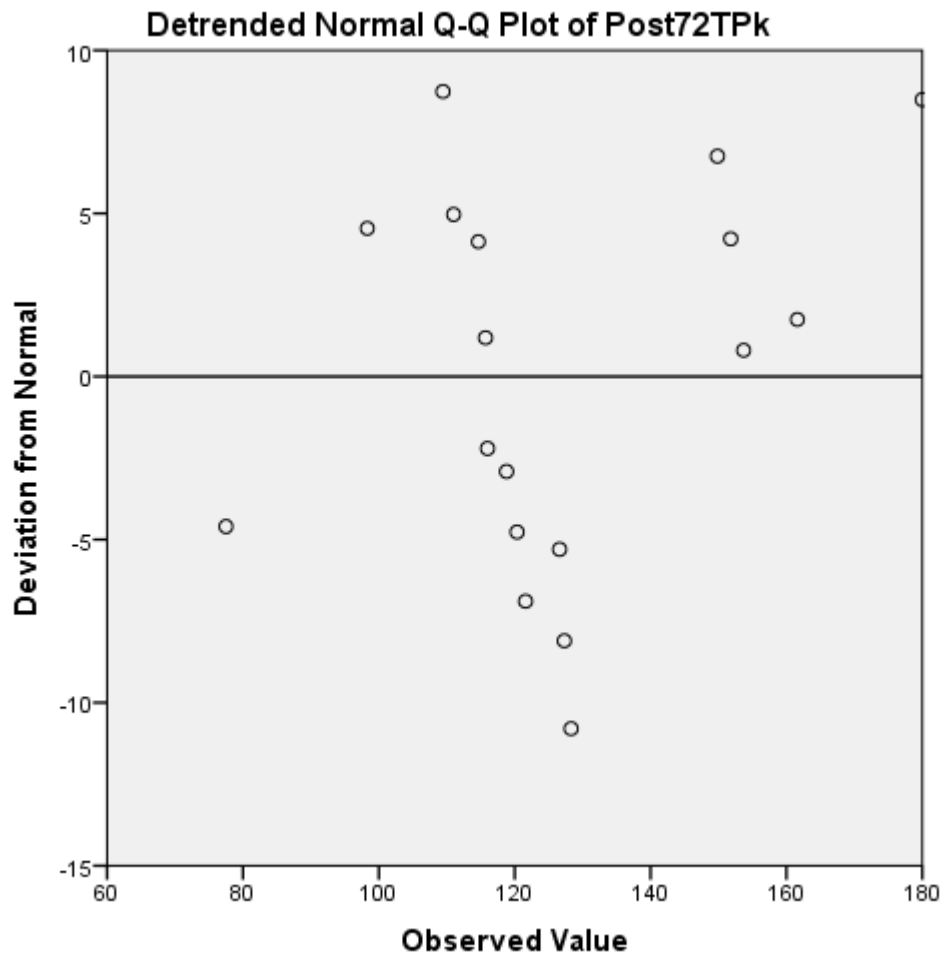












**1.3: PkT60 Localised Repeated Measures ANOVA:**

```
GLM PreTPk postTPk Post24TPk Post48TPk Post72TPk
/WSFACTOR=time 5 Polynomial
/MEASURE=ecc
/METHOD=SSTYPE(3)
/PLOT=PROFILE(time)
/EMMEANS=TABLES(time) COMPARE ADJ(BONFERRONI)
/PRINT=DESCRIPTIVE ETASQ
/CRITERIA=ALPHA(.05)
/WSDESIGN=time.
```

**General Linear Model**

**Notes**

Output Created		02-AUG-2015 21:56:56
Comments		
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	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	18
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.



Syntax	GLM PreTPk postTPk Post24TPk Post48TPk Post72TPk /WSFACTOR=time 5 Polynomial /MEASURE=ecc /METHOD=SSTYPE(3) /PLOT=PROFILE(time)  /EMMEANS=TABLES(time) COMPARE ADJ(BONFERRONI) /PRINT=DESCRIPTIVE ETASQ /CRITERIA=ALPHA(.05) /WSDSIGN=time.
Resources	Processor Time 00:00:00.18 Elapsed Time 00:00:00.00

**Within-Subjects Factors**

Measure: ecc

time	Dependent Variable
1	PreTPk
2	postTPk
3	Post24TPk
4	Post48TPk
5	Post72TPk

**Descriptive Statistics**

	Mean	Std. Deviation	N
PreTPk	139.2728	21.74023	18
postTPk	117.1944	19.48864	18
Post24TPk	109.2056	16.05119	18
Post48TPk	115.3778	14.82031	18
Post72TPk	126.8056	24.53958	18

**Multivariate Tests<sup>a</sup>**

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
time	Pillai's Trace	.777	12.189 <sup>b</sup>	4.000	14.000	.000	.777
	Wilks' Lambda	.223	12.189 <sup>b</sup>	4.000	14.000	.000	.777
	Hotelling's Trace	3.483	12.189 <sup>b</sup>	4.000	14.000	.000	.777
	Roy's Largest Root	3.483	12.189 <sup>b</sup>	4.000	14.000	.000	.777

a. Design: Intercept

Within Subjects Design: time

b. Exact statistic

**Mauchly's Test of Sphericity<sup>a</sup>**

Measure: ecc

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon <sup>b</sup>		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	.346	16.381	9	.061	.691	.839	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

**Tests of Within-Subjects Effects**

Measure: ecc

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
time	Sphericity Assumed	9921.023	4	2480.256	10.564	.000	.383
	Greenhouse-Geisser	9921.023	2.764	3588.915	10.564	.000	.383
	Huynh-Feldt	9921.023	3.355	2957.227	10.564	.000	.383
	Lower-bound	9921.023	1.000	9921.023	10.564	.005	.383
	Error(time)	Sphericity Assumed	15965.137	68	234.781		
	Greenhouse-Geisser	15965.137	46.994	339.727			
	Huynh-Feldt	15965.137	57.032	279.932			

Lower-bound	15965.137	17.000	939.126			
-------------	-----------	--------	---------	--	--	--

**Tests of Within-Subjects Contrasts**

Measure: ecc

Source	time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
time	Linear	1288.120	1	1288.120	4.097	.059	.194
	Quadratic	8471.713	1	8471.713	29.766	.000	.636
	Cubic	140.468	1	140.468	.570	.461	.032
	Order 4	20.723	1	20.723	.221	.644	.013
Error(time)	Linear	5344.342	17	314.373			
	Quadratic	4838.422	17	284.613			
	Cubic	4191.107	17	246.536			
	Order 4	1591.265	17	93.604			

**Tests of Between-Subjects Effects**

Measure: ecc

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1330160.587	1	1330160.587	1339.818	.000	.987
Error	16877.468	17	992.792			

**Estimated Marginal Means**

time

**Estimates**

Measure: ecc

time	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	139.273	5.124	128.462	150.084
2	117.194	4.594	107.503	126.886
3	109.206	3.783	101.223	117.188
4	115.378	3.493	108.008	122.748
5	126.806	5.784	114.602	139.009

### Pairwise Comparisons

Measure: ecc

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig. <sup>b</sup>	95% Confidence Interval for Difference <sup>b</sup>	
					Lower Bound	Upper Bound
1	2	22.078*	3.782	.000	9.892	34.265
	3	30.067*	5.468	.000	12.445	47.689
	4	23.895*	6.068	.011	4.342	43.448
	5	12.467	5.858	.482	-6.410	31.344
2	1	-22.078*	3.782	.000	-34.265	-9.892
	3	7.989	4.786	1.000	-7.434	23.412
	4	1.817	5.292	1.000	-15.237	18.870
	5	-9.611	4.312	.396	-23.506	4.284
3	1	-30.067*	5.468	.000	-47.689	-12.445
	2	-7.989	4.786	1.000	-23.412	7.434
	4	-6.172	3.105	.632	-16.177	3.833
	5	-17.600	5.474	.051	-35.239	.039
4	1	-23.895*	6.068	.011	-43.448	-4.342
	2	-1.817	5.292	1.000	-18.870	15.237
	3	6.172	3.105	.632	-3.833	16.177
	5	-11.428	6.035	.754	-30.875	8.019
5	1	-12.467	5.858	.482	-31.344	6.410
	2	9.611	4.312	.396	-4.284	23.506
	3	17.600	5.474	.051	-.039	35.239
	4	11.428	6.035	.754	-8.019	30.875

Based on estimated marginal means

\*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

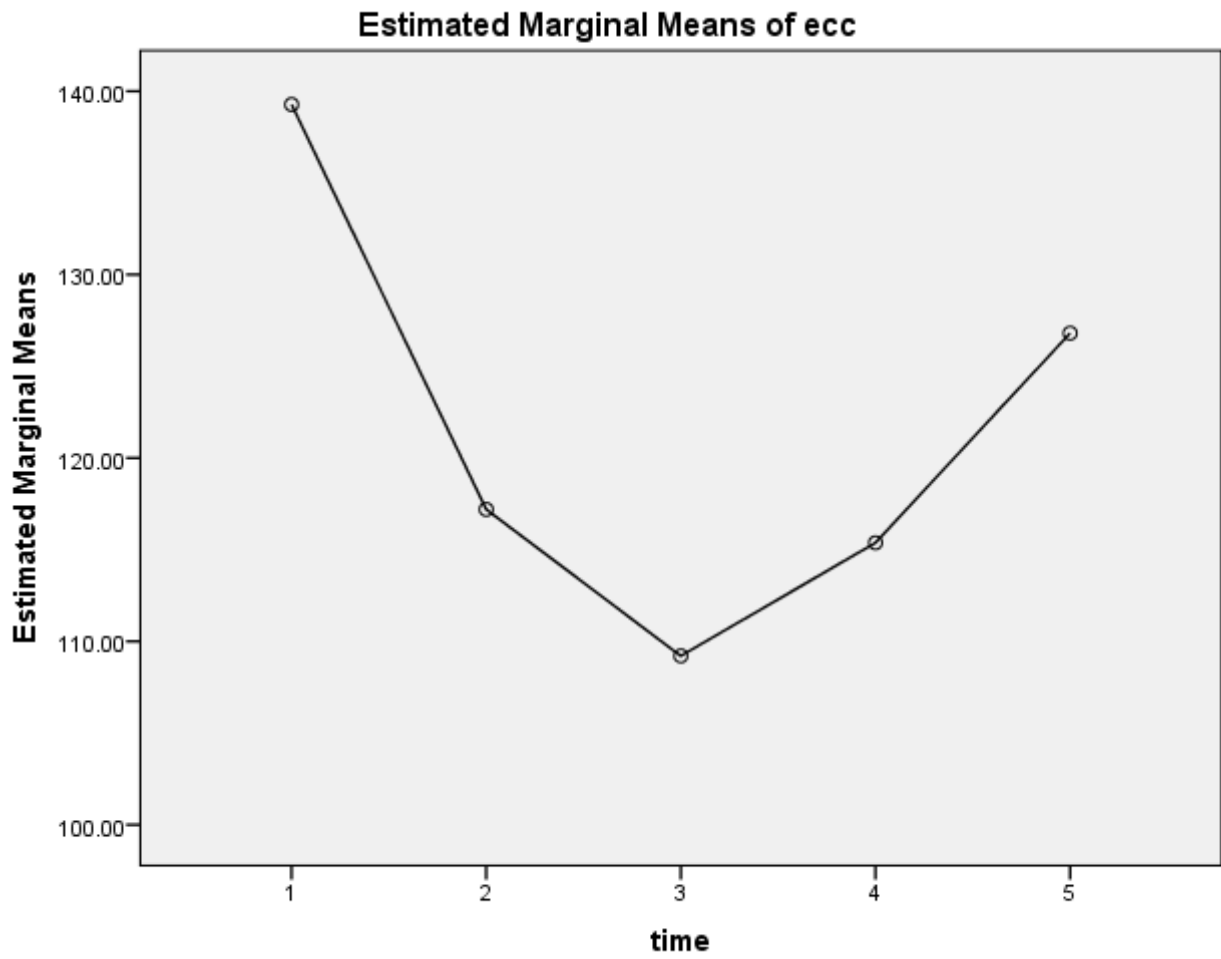
### Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.777	12.189 <sup>a</sup>	4.000	14.000	.000	.777
Wilks' lambda	.223	12.189 <sup>a</sup>	4.000	14.000	.000	.777
Hotelling's trace	3.483	12.189 <sup>a</sup>	4.000	14.000	.000	.777
Roy's largest root	3.483	12.189 <sup>a</sup>	4.000	14.000	.000	.777

Each F tests the multivariate effect of time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

**Profile Plots**



**2: Copy of Consent Letter for Use of Photographs within Methods:**

Dear participant,

During the completion of this study, pictures were taken of you performing testing on the Biodex Stability System (dynamic stability measures) and Isokinetic Dynamometer (eccentric strength measures). These photographs may be utilised within the thesis to explain the methods utilised and provide a visual aid for how the testing was performed. The pictures will remain anonymous and will only be utilised for the purposes of this research.

If you consent to the photographs being utilised in this study please can you clearly print your name in bold capital letters, sign and date below.

Many Thanks



David Rhodes

I **MATT GREIG** consent to the use of photographs of myself performing testing on the Biodex Stability System and Isokinetic Dynamometer for the purposes of this research.

Date: 01/07/2017    Signature:

